Watercom Pty Ltd

DRAINS
User Manual

A manual on the *DRAINS* program
for urban stormwater drainage system
design and analysis

by

Geoffrey O'Loughlin and Bob Stack

This manual coincides with *DRAINS* Version 2014.11
It is available electronically and on paper and is updated regularly
- to download a PDF file of the latest version,
visit www.watercom.com.au.

Sydney

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WELCOME

This manual, available in both printed and electronic forms, provides the information you need to run the *DRAINS* program to design and analyse urban stormwater drainage systems. Together with the Help system that accompanies *DRAINS*, it will guide you to understand what *DRAINS* can do, and how to use it to model many situations. The data files included in the **`Manual Example Files`** folder among the files supplied with *DRAINS*, which are also obtainable from www.watercom.com.au, can be used to explore the operation of *DRAINS*.

The manual covers the operation of Version 2014.07 of *DRAINS*. An appendix provides information on the *DRAINS* Viewer, a free program that can be used to review *DRAINS* models and result files.

DRAINS uses hydrological and hydraulic methods developed by generations of engineers. If you have formal training in water engineering and experience in using models and encountering practical problems, you should find the program easy to use and to interpret.

If you are a beginner in the fields of hydrology, hydraulics or stormwater system design, or are out of practice, this manual and the Help system will assist you towards understanding the program's operations and outputs. *DRAINS* can apply four types of alternative hydrological models and two hydraulic modelling procedures.

This manual can be used as a learning guide for *DRAINS* or as a reference manual that you can dip into. There is an index at the end, and you can use PDF search functions to find topics in the electronic version. Most displays of screens are in Microsoft Windows 7 style; these displays may appear different in XP or 'classic style', but the contents are the same.

Chapter 1 describes what *DRAINS* is and does, and how it can be installed. To get you started, it provides a simple example that takes you through the steps of entering data, running the program, and inspecting some of its outputs. (The examples supplied run with the demo version of *DRAINS*, and cover most of the methods available in *DRAINS.*)

Chapter 2 deals with the many items and facilities in *DRAINS*. It presents the menus that control operation, the tools that define drainage system components (pits, pipes, etc.), and the data bases used to store standard data. It describes the data required for all components. To illustrate these, it works with a larger example involving both pipes and open channels.

Chapter 3 is about processes. It describes the options within *DRAINS* for inputting and displaying information, running the program, outputting data and results, and obtaining help.

Chapter 4 describes how *DRAINS* operates, covering computing and computational aspects. It also describes how *DRAINS* can be applied to design and analysis tasks, indicating how runs can be made and how results can be interpreted.

Chapter 5 provides the technical background to *DRAINS* and the methods that it uses. There are explanations and references relating to material on rainfall data, overland flows, pit inlet capacities and pressure change coefficients, detention basins, culverts and bridges.

The examples that were explained in earlier versions of this manual are now included in the *DRAINS* Help system. They use files that are available at C:\Program Files\Drains or C:\Program Files (x86)\Drains.

Previous versions of this manual described some features that have become obsolete and have been deleted. To avoid confusion, these descriptions are not given here, but the information remains in the *DRAINS* Help system to provide guidance when models created by earlier versions of *DRAINS* are revisited

As *DRAINS* develops and new features are added, there will be revisions of this manual, available electronically from www.watercom.com.au and on paper.

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1. INTRODUCTION TO *DRAINS*

1.1 Outline

1.1.1 Description

DRAINS is a multi-purpose Windows program for designing and analysing urban stormwater drainage systems and catchments. It was first released in January 1998 and is marketed by Watercom Pty Ltd, based in Wooli, NSW.

DRAINS can model drainage systems of all sizes, from small to very large (up to 10 km^2 using sub-catchments with ILSAX hydrology, and greater using storage routing model hydrology). Working through a number of time steps that occur during the course of a storm event, it simulates the conversion of rainfall patterns to stormwater runoff hydrographs and routes these through networks of pipes, channels and streams. In this process, it integrates:

- design and analysis tasks,
- hydrology (four alternative models) and hydraulics (two alternative procedures),
- closed conduit and open channel systems,
- headwalls, culverts and other structures,
- stormwater detention systems, and
- large-scale urban and rural catchments.

Within a single package, *DRAINS* can carry out hydrological modelling using ILSAX, rational method and storage routing models, together with unsteady hydraulic modelling of systems of pipes, open channels and, and in the premium hydraulic model, surface overflow routes. It includes an automatic design procedure for piped drainage systems, connections to CAD and GIS programs, and an in-built Help system. Figure 1.1 shows areas where *DRAINS* can be used.

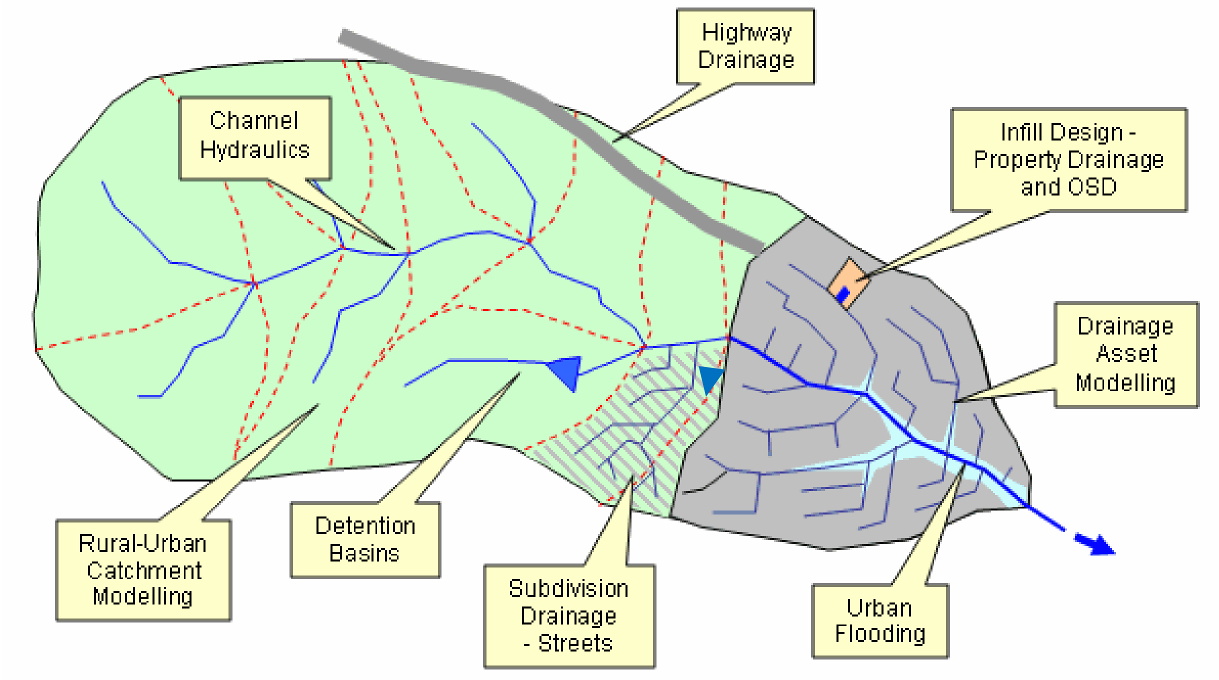


Figure 1.1 *DRAINS* Applications

Three significant functions that are not included in *DRAINS* are (a) continuous modelling over long periods including wet and dry conditions, (b) water quality modelling, and (c) 2-dimensional unsteady flow modelling.

DRAINS is continuously being improved and expanded. Although users need to adapt to new features and modes of operation in the program, this continuing development process provides benefits from improvements to *DRAINS*' modelling techniques and breadth of coverage.

DRAINS is available in versions for 20, 50 and unlimited numbers of pipes or channels. The ILSAX hydrology or rational method can be chosen. Optional ILSAX or rational method procedures, storage routing models, GIS capabilities and unsteady flow hydraulics in overflow routes are available at extra cost. Current prices are available from Bob Stack of Watercom Pty Ltd on (02) 6649 8005 or bobstack@watercom.com.au.

1.1.2 Modelling Aspects

(a) Hydrology to Estimate Flows

The ILSAX hydrological model, illustrated in Figure 1.2, is the original model used to simulate the operation of urban stormwater drainage systems in *DRAINS*. It comes from the ILSAX program (O'Loughlin, 1993), described in Section 5.3.2. This model uses time-area calculations and Horton infiltration procedures to calculate flow hydrographs from sub-catchments. The various sub-catchment flows are combined and routed through a pipe and channel system. Calculations are performed at specified times after the start of each storm, using time intervals of one minute or less. At each time step, a hydraulic grade line analysis is performed throughout the drainage network, determining flowrates and water levels.

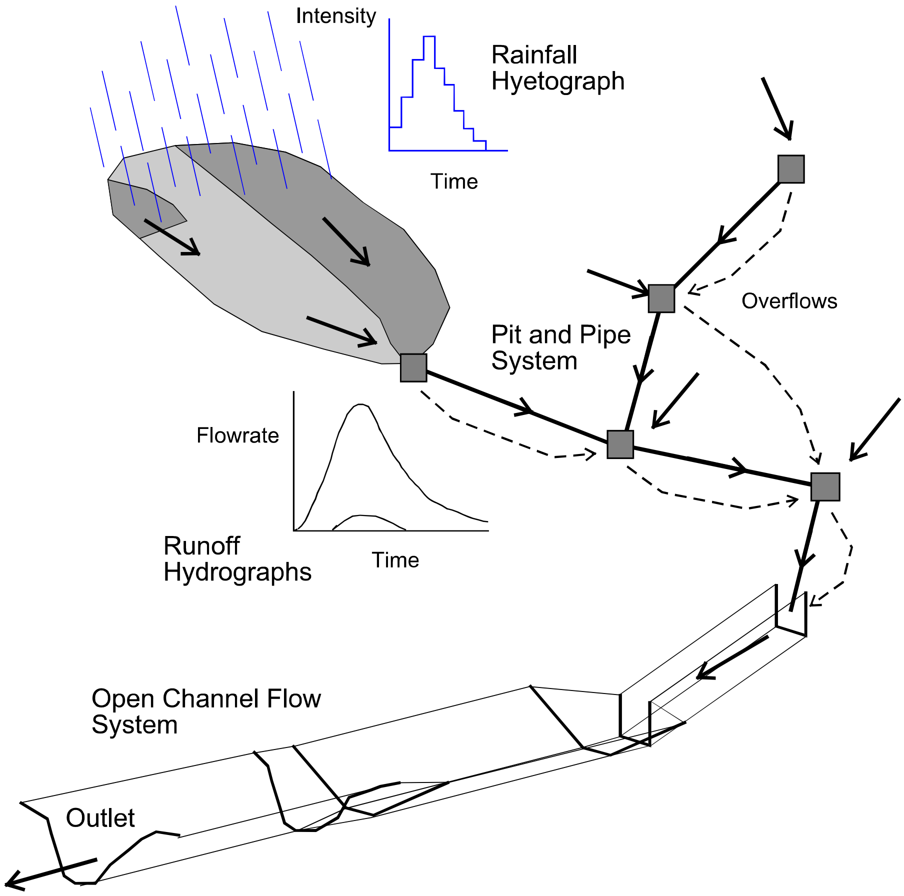


Figure 1.2 Operation of the *DRAINS* Rainfall-Runoff Simulation Model Incorporating the ILSAX Hydrological Model and Hydraulic Calculations

The design of a piped drainage system can be performed automatically, followed by an analysis, and results can be checked, viewed and exported as CAD (computer aided drafting) files, GIS (geographical information system) files and spreadsheet tables.

In addition to the ILSAX model, three other hydrological models are available as options in *DRAINS*:

(a) Peak flowrates can be calculated by the rational method, traditionally used for calculating flowrates for piped urban drainage design. Using the formula Q=C.I.A, it converts a statistical rainfall intensity I to a flowrate Q using a runoff coefficient C and catchment area A (see Section 5.3.3). The rational method's main drawback that it does not calculate flow hydrographs, and it is gradually being superseded by hydrograph-producing methods. *DRAINS* includes a search procedure that determines the time duration that gives the greatest value of Q = C.I.A, thus resolving 'partial area' problems.

(b) An optional, 'extended' rational method (ERM) model that produces flow hydrographs based on rational method calculations is also provided with the rational method, for modelling detention systems.

(c) *DRAINS* incorporates optional storage routing models of the type used in the RORB, RAFTS and WBNM programs that have been used in Australia since the 1970s, and are applicable to broad-scale rural and urban catchments of virtually any size. As shown in Figure 1.3, they involve the division of a catchment into sub-catchments based on streams and internal ridge lines.

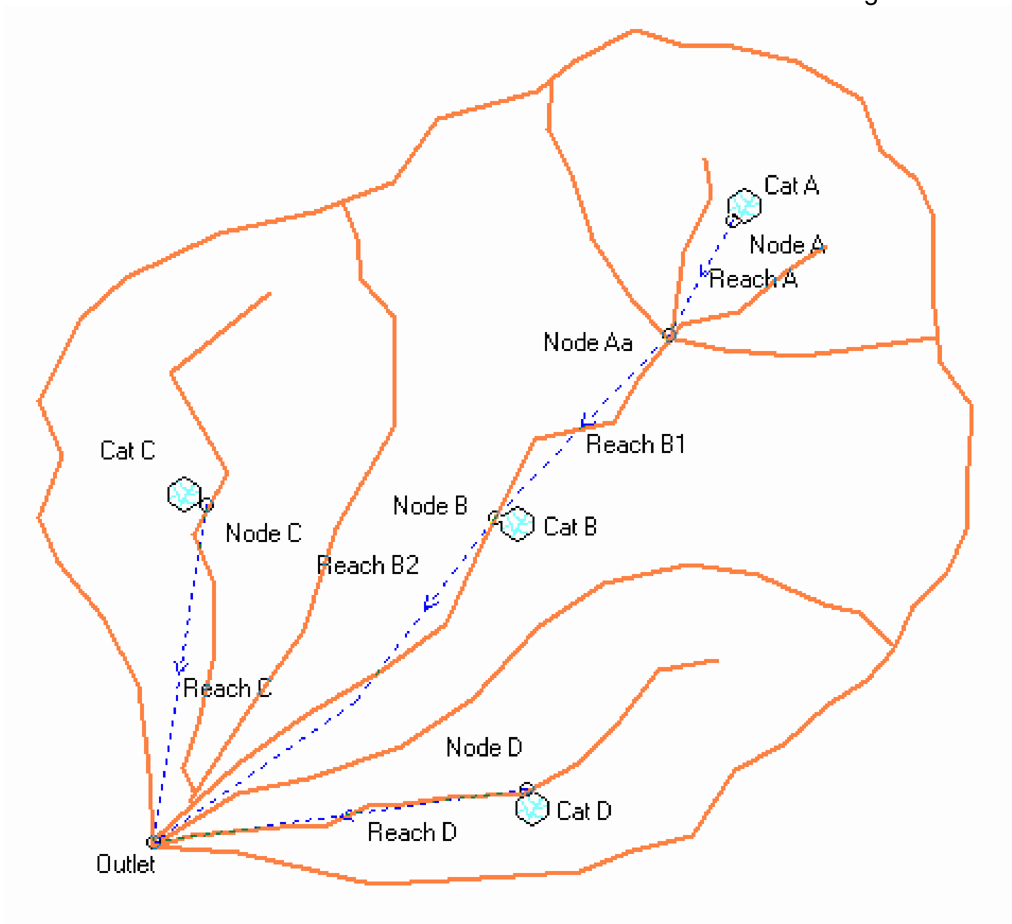


Figure 1.3 Layout of a RORB style of Storage Routing Model within *DRAINS*

Storage routing models treat sub-catchments and stream reaches as storages (similar to reservoirs or detention basins) that can be modelled by the non-linear equation, $S = k.Q^m$, where S is the storage in an element, Q is the flow or discharge out of the element, and k and m are model parameters. These models work downwards through a catchment, adding runoff from the various sub-catchments and performing routing catchments that reshape the hydrographs.

The runoff routing modelling facilities in *DRAINS* can be configured to emulate the RORB, RAFTS and WBNM modelling structures. They can also be combined with ILSAX sub-catchments and open channel hydraulic calculations, so that quite diverse flooding and urban drainage systems can be described.

(b) Hydraulic Calculations for Pipes, Open Channels and Surface Overflows

The procedures in *DRAINS* originally were intended to be of a medium level of complexity, providing stable, fast and sufficiently accurate methods to compute flowrates and water surface profiles. The needs of users have prompted considerable advances.

The original *basic hydraulic model* combined (i) hydraulic grade lines (HGLs) projected backwards from tailwater levels at drainage system outlets with (ii) a pressure pipe calculation procedure, to calculate flowrates and HGL levels at pits and other locations using a quasi-unsteady process. *DRAINS* then computed the characteristics of surface overflows that cannot be carried by pipes.

This model has been replaced by a one-dimensional unsteady flow procedure. In the *standard hydraulics model*, this is applied to pipe and open channel flows, and in the *premium hydraulic model*, surface overflows are also modelled by full unsteady flow calculations.

(c) Additional Information on Models

A more detailed coverage of the hydrological and hydraulic models available in *DRAINS* is provided in Chapter 5. These procedures reflect Australian urban stormwater drainage management practice, which considers hydrological and hydraulic features in considerable detail, as described in this manual and in the *DRAINS* Help system. *DRAINS* is also adaptable for use outside Australia. The ILSAX model is based on the American ILLUDAS program, using the U.S. Soil Conservation Service soil classification, and the Horton infiltration model is the same as that used in the US EPA Stormwater Management Model (SWMM) program (Huber and Dickinson, 1998). The rational method and ERM procedures are similar to one applied in the U.S. The hydraulic procedures are the same as those used in all English-speaking countries, using Colebrook-White and Manning's equations.

1.1.3 Computer Aspects

DRAINS follows Microsoft Windows conventions and runs on all version of the Windows operating system, from Windows 95 to Windows 7. PC users will find the standard Main Window, menu bar, toolbar and Help system easy to navigate. There are four alternative forms of data entry:

- by drawing drainage system components on the screen and inserting information for each component in property sheets,
- by entering data from ILSAX files, CAD drawing files or GIS files,
- by direct entry from other programs such as 12d, CADApps Advanced Road Design and MX, and
- by modifying spreadsheet output files created by *DRAINS*, or building such files directly in a spreadsheet program or as an exported file from another program.

There is also a large choice of outputs - screen print-outs, CAD, GIS and spreadsheet files.
In most cases, revised data can be transferred back to the originating programs using these files.

Installation and updating of *DRAINS* is quick and easy using a self-extracting file named **`DainsSetup.exe`** that can be supplied on CD-ROM or downloaded from www.watercom.com.au. The file installs the latest release version of *DRAINS*, which also operates as a demonstration program with a limit of five pipes or channels, and restrictions on changes to detention basins and culverts.

When installed on a PC using Microsoft Windows, the program resides in the folder **`C:\Program Files\Drains\Program`**, along with related files. It also places a default data base file named **`Drains.db1`** in **`C:\ProgramData\Drains`** to meet Microsoft Vista requirements' At present, the **`Drains.exe`** file is about 4 Mb in size, and is accompanied by a HTML Help file of 4 Mb.

To run with capabilities beyond those of the demonstration version, a hardware lock or dongle must be inserted into a USB port, or with earlier types, the 25 pin printer port of the PC. *DRAINS* can be installed and run on any PC or server system to which a hardware lock has been attached. The hardware lock will control the number of conduits that can be modelled (20, 50 and unlimited), and whether rational method, storage routing GIS modelling or premium hydraulic modelling facilities are implemented.

The *DRAINS* Viewer described in Appendix A is a separate program, but operates in the same way as *DRAINS*. Both programs can be opened at the same time. The Viewer is installed from a self-extracting file, and users can navigate through *DRAINS* models, property sheets and outputs of results in the same way as *DRAINS*. However, they cannot modify or run models. There is no size limitation on the Viewer and it can be freely distributed. To read the latest *DRAINS* models, the Viewer needs to be periodically updated. To obtain the latest version, contact Bob Stack or Geoffrey O'Loughlin at the numbers given in the next section.

Microsoft Vista and Windows 7 impose restrictions that may affect users' ability to change the standard data base stored in the **`Drains.db1`** file (see Section 2.4.2). The user should have permission to modify files in **`C:\ProgramData\Drains`**.

1.1.4 Support

For support, contact Watercom Pty Ltd at phone/fax (02) 6649 8005 or bobstack@watercom.com.au. Training workshops are conducted by Dr. Geoffrey O'Loughlin, who can be contacted on phone (02) 9570 6119 or 0438 383 841, fax (02) 9570 6111 and geoff.oloughlin@tpg.com.au. They are communicated to *DRAINS* users by e-mail, and advertised by mail-outs to organisations involved with urban stormwater management.

1.1.5 Installation

If you are setting up the demonstration version, or updating a *DRAINS* program that is already installed, you only need the file **`DrainsSetup.exe`**, which can be downloaded from the website www.watercom.com.au or obtained on CD.

Click your mouse on the icon for **`DrainsSetup.exe`** and, when prompted, enter the password provided by Watercom Pty Ltd, or enter 'DEMO' to install the demonstration version. Then follow the instructions, acknowledging the Conditions of Use.

For the first installation of *DRAINS* on a PC that is to be used with a hardware lock, you should install from the CD-ROM provided when *DRAINS* is purchased. The USB locks that are currently supplied do not require a driver.

Installations can be made on any number of PCs. Running *DRAINS* requires that the moveable hardware lock or dongle be connected to the PC's USB or printer ports. Locks are programmed to model certain sizes of drainage network (up to 20, 50 or unlimited links), to implement additional rational method, ILSAX and storage routing model calculations, to import and export data from GIS files and to undertake full premium hydraulic calculations. *DRAINS* can be uninstalled in the usual way for Windows programs.

The version number of the *DRAINS* program being used can be found in the **About *DRAINS*….** Option in the **Help** menu. The **License Details** item provides information on the capabilities of the attached hardware lock.

The *DRAINS* Viewer installs in the same way as the demonstration version of *DRAINS*. No password is required.

1.1.6 Starting Up

Once installed, *DRAINS* can be opened by:

- using the **Start** menu, selecting Programs and choosing *DRAINS*,
- clicking on a *DRAINS* shortcut if one is created on your desktop (This may be necessary with some server systems.), or
- clicking on Drains.exe in the **`C:\Program Files\Drains\Program`** folder.

When opened, the Main Window of *DRAINS* appears as shown in Figure 1.4.

You can define a drainage system graphically on this blank screen by drawing components such as pits and pipes, using the facilities in the menus and toolbar located at the top.

To operate *DRAINS*, you can enter data directly using the keyboard and mouse, or open or import an existing file from the **File** menu. If you are entering an entirely new system, you must follow the steps that are explained in detail in the following section.

1.2 Examples of *DRAINS* in Operation

1.2.1 Running a Model of a Simple Pipe System

This example illustrates how a pipe system, assumed to be located at Orange, New South Wales, can be set up in *DRAINS* and how design and analysis runs can be made. You will learn best by constructing the model in the demonstration or full versions of *DRAINS* using the instructions set out below. Alternatively, you can inspect and run the finished model files **`Orange1.drn`** and **`Orange2.drn`** provided in the set of examples accompanying this manual.

The instructions do not cover all *DRAINS* options or procedures, but are adequate to set up this model.

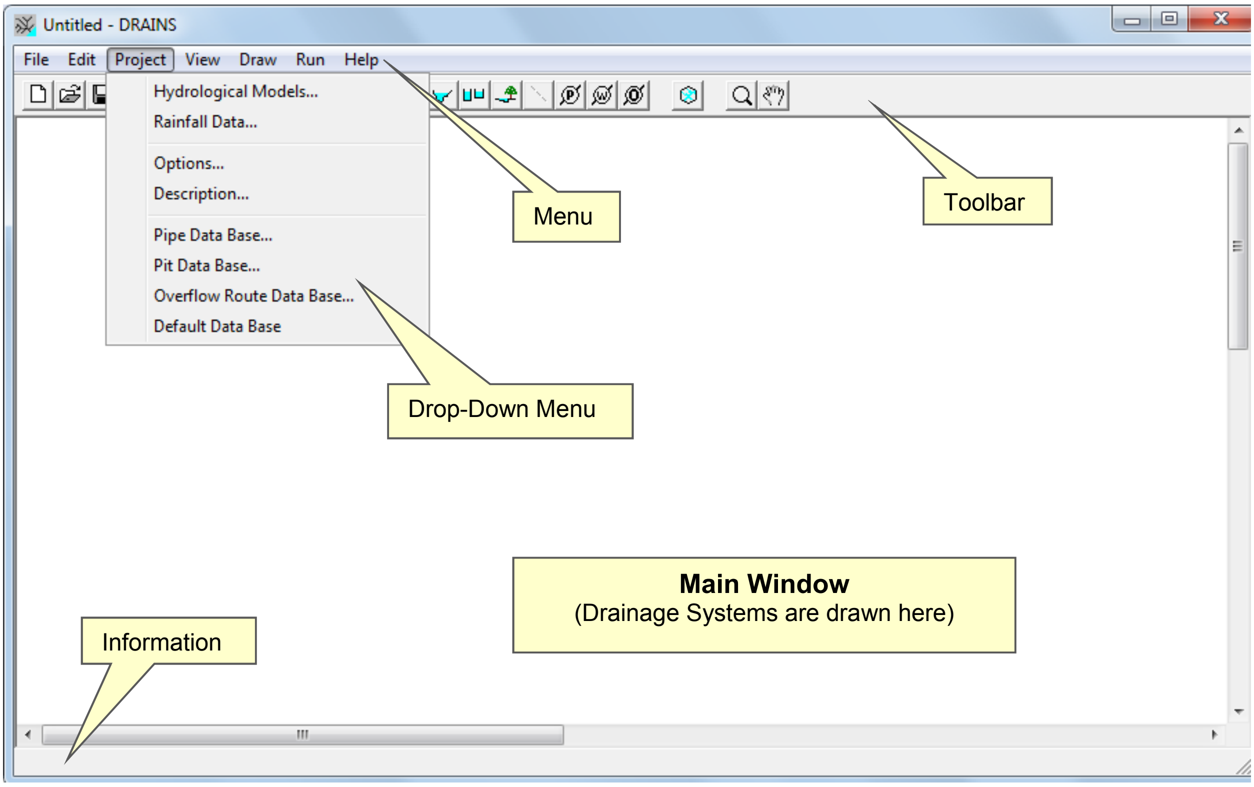


Figure 1.4 The Main *DRAINS* Window with the Project Menu Selected

(a) Defining Hydrological Models, Rainfall Data and Other Options

The hydrological model, rainfall patterns and component data bases should be established first. Most of this information can be changed later. If you open and close an existing *DRAINS* model, the hydrological model and rainfall from that model will remain. To start afresh, you need to exit from *DRAINS* and start up again. In this case, the databases for the hydrological model and rainfall data will be empty, while those for pipes, pits and overflow routes will be taken from the file **Drains.db1**, located in the **`C:\ProgramData\Drains.`**

From the **Project** menu at the top of the screen you can select **Hydrological Models….** The window in Figure 1.5 appears, showing a dialog that is used to establish hydrological models. (Not all of the options shown may be available with your hardware lock.)

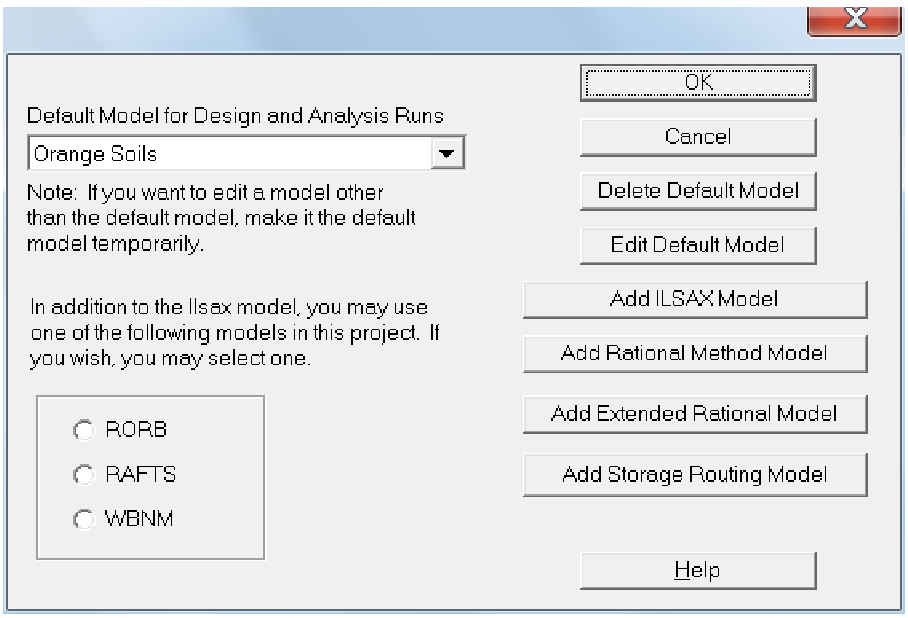


Figure 1.5 The Hydrological Model Specification Dialog Box

ILSAX hydrology is used in this example. Clicking the **Add ILSAX Model** button opens the property sheet shown in Figure 1.6, in which the characteristics of the hydrological model can be entered.

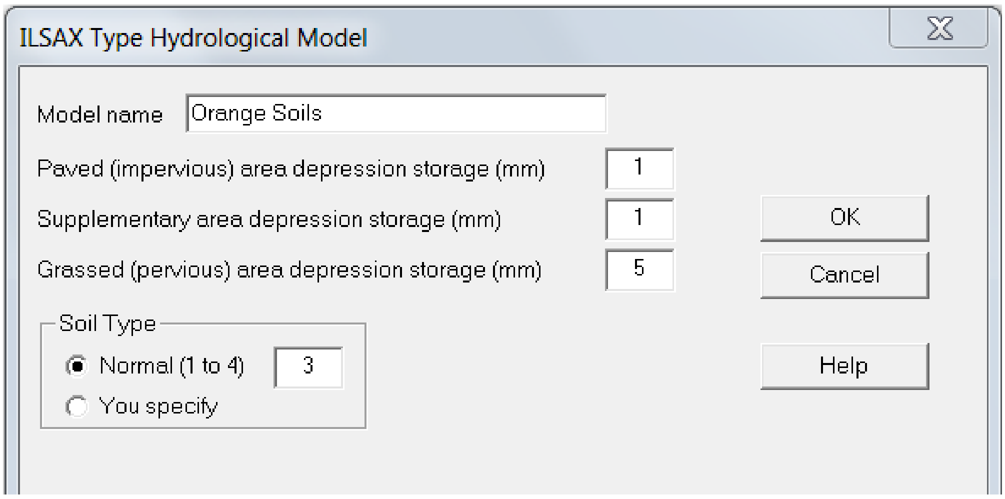


Figure 1.6 ILSAX Type Hydrological Model Property Sheet (Top Portion)

Enter the name and numbers shown. These will be explained later, but if you require an immediate explanation, press the **Help** button to open the Help screen shown in Figure 1.7.

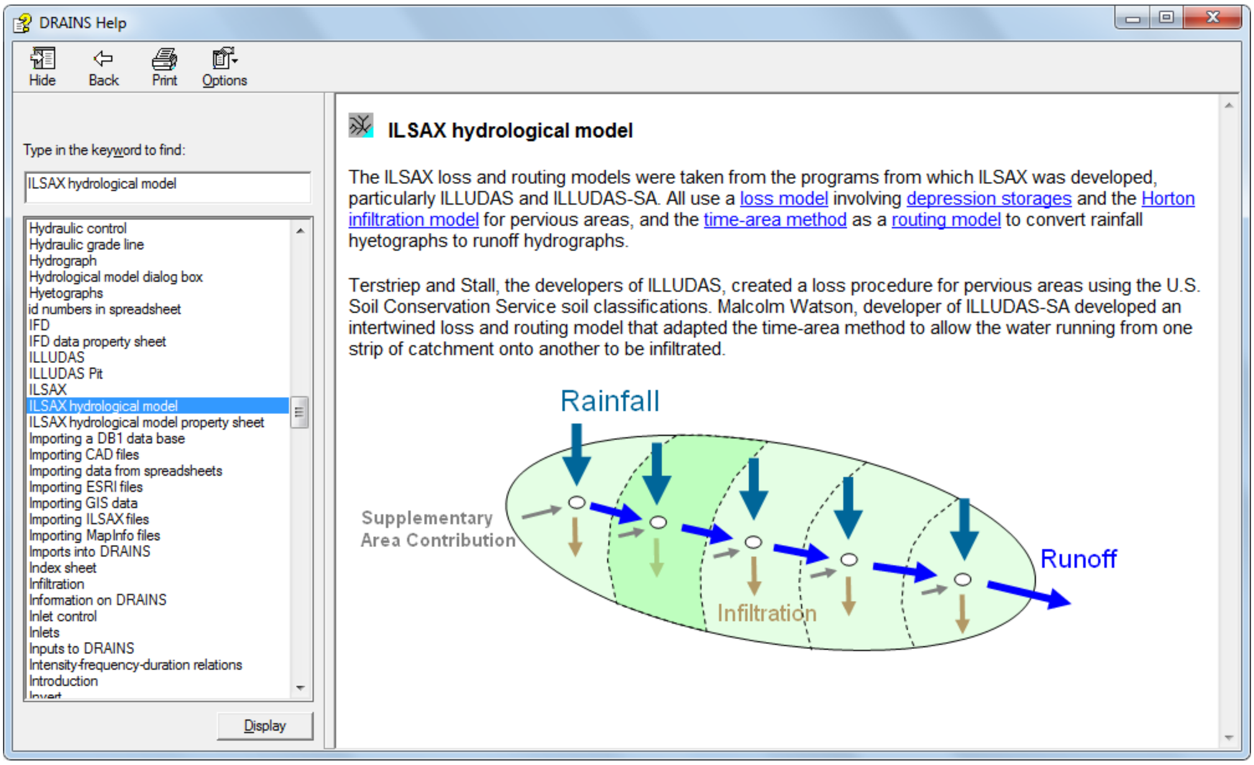


Figure 1.7 Help Window opened from the ILSAX Hydrological Model Property Sheet

You should then click **OK** in the property sheet and the Hydrological Model Specification dialog box, ensuring that 'Orange Soils' is defined as the default model in the drop-down list box at the top left corner of Figure 1.5.

Next, you must define the rainfall patterns to be used, using the **Rainfall Data…** option in the **Project** menu. This opens the window shown Figure 1.8, in which you can set up a data base of rainfall patterns or hyetographs. In this example, two patterns are to be set up, both of 25 minutes duration, for average recurrence intervals (ARIs) of 2 years and 100 years, corresponding to average intensities of 40.2 and 101 mm/h. For most design and analysis tasks in Australia, the required rainfall data will come from *Australian Rainfall and Runoff* (Institution of Engineers, Australia, 1987) or from updated intensity-frequency-duration data to be made available on the Bureau of Meteorology website, www.bom.gov.au.

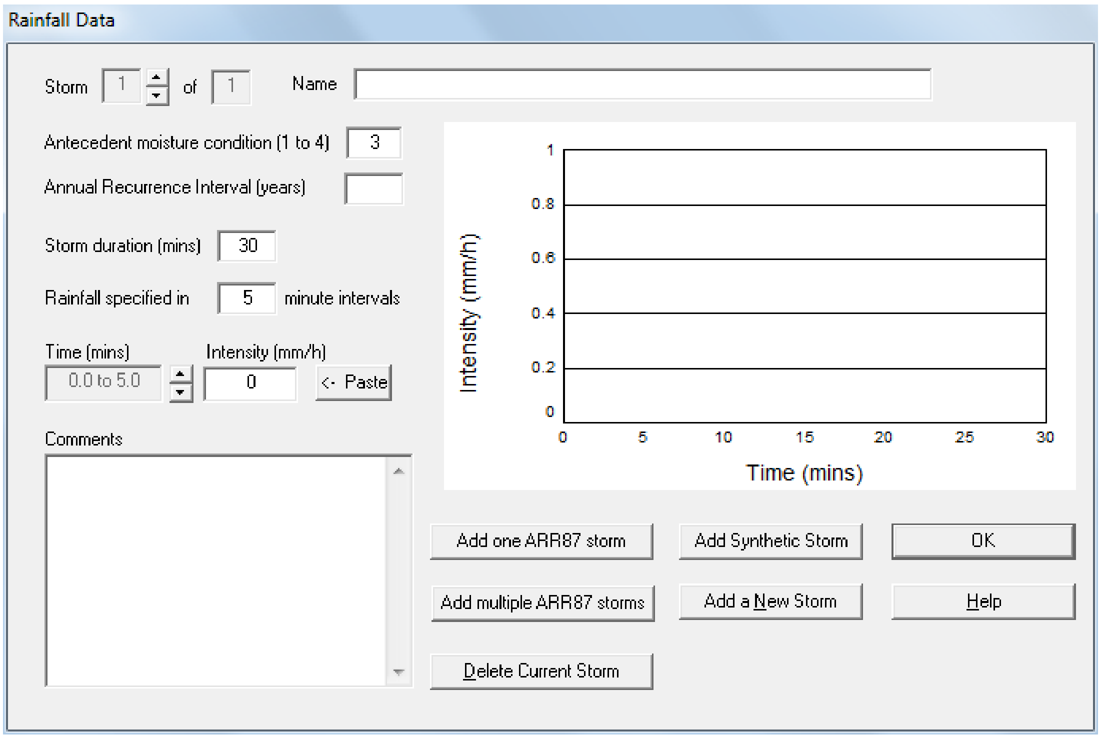


Figure 1.8 Rainfall Data Property Sheet

Storm patterns or hyetographs can be defined easily in *DRAINS* by clicking the **Add one ARR87 Storm** button, which opens the dialog box shown in Figure 1.9.

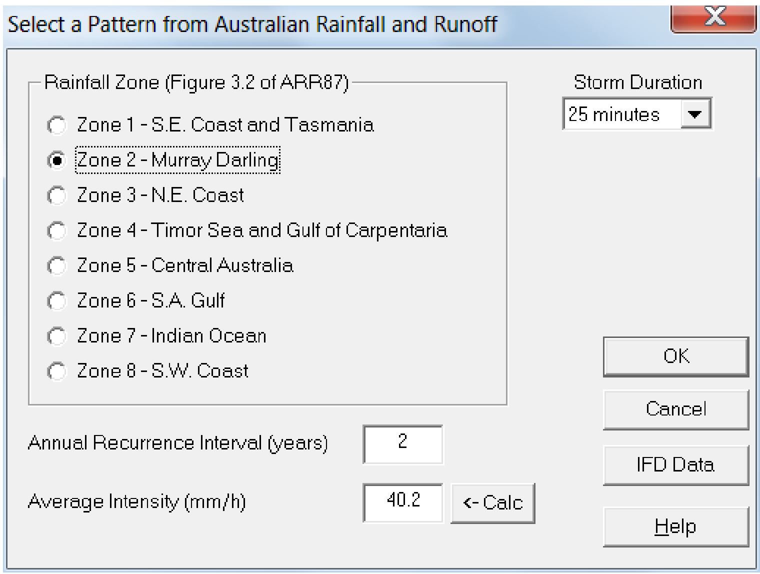


Figure 1.9 *Australian Rainfall and Runoff* Pattern Dialog Box

Enter the information shown in this figure and press the **OK** button. The pattern will be displayed in the Rainfall Data property sheet, as shown in Figure 1.10. (Note that there are other ways of entering rainfall data, described in Section 2.4.4).

Next, change the antecedent moisture condition value in the Rainfall property sheet to 2.5. Set up a second pattern using the same process, this time for an ARI of 100 years and an intensity of 101 mm/h. Then click the **OK** button.

The next step is to select storms from the data base to be used for design and for analysis. This is done using the **Select Minor Storms** option in the **Project** menu, which opens the dialog box shown in Figure 1.11. Click the **Selected storms** button in the top left corner and then click the downwards arrow on the first drop down list box to show the names of the rainfall patterns in the data base. For this example, click on the 2 year ARI, 25 minute pattern to select this storm as the one to be used to design the pipe system.

Close this dialog box by clicking **OK**, and then follow the same procedure with **Select Major Storms** to select the 100 year ARI, 25 minute storm for major storm runs.

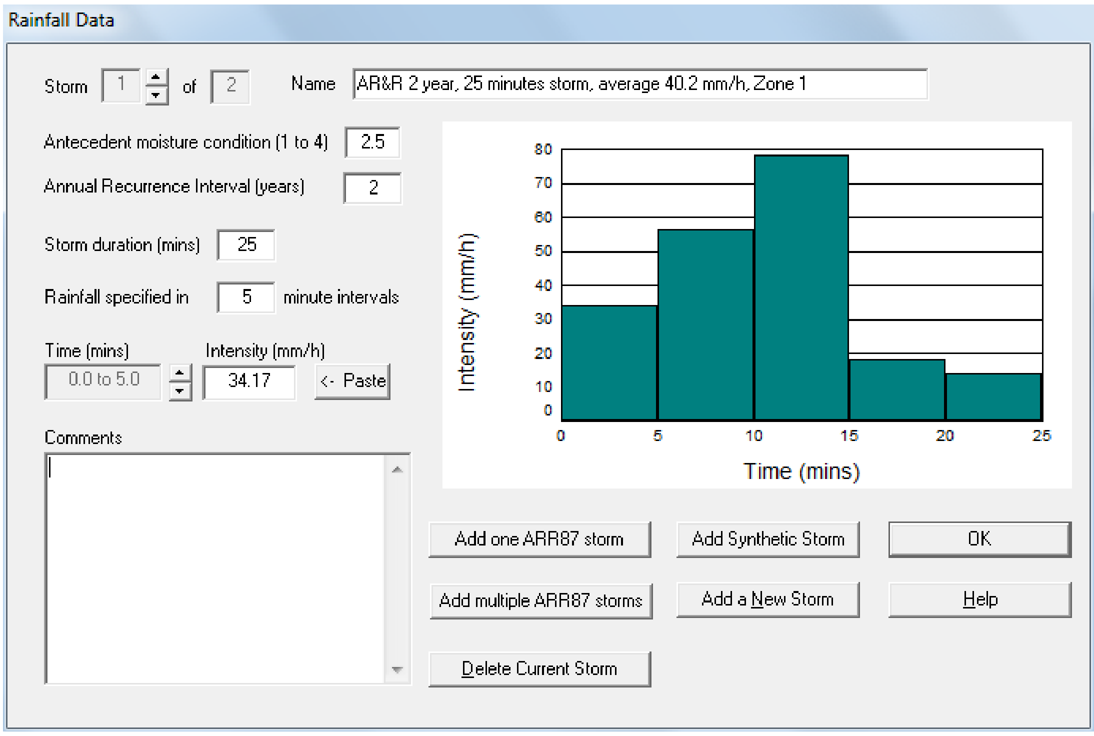


Figure 1.10 2 Year ARI, 25 Minute Rainfall Pattern for Orange, NSW

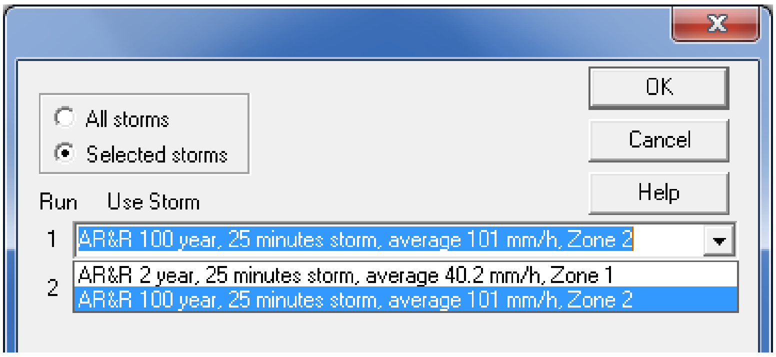


Figure 1.11 Select Minor Storms Dialog Box

(The design process defines the pipe sizes and depths needed to carry runoff from minor ARI storms satisfactorily, while meeting certain criteria. The system must also 'fail-safe' in runoff from major ARI storms. The system performance is checked using various analyses.)

Now choose **Options …** in the **Project** menu to open the sheet shown in Figure 1.12. This sets the values of parameters used in design calculations. The only items to be entered in the present example are the blocking factors - enter 0.5 for sag pits and 0.0 for on-grade pits.

With this model, you will be using New South Wales pits. To select these, choose the **Default Data Base** option in the **Project** menu. The dialog box shown in Figure 1.13 appears, allowing you to select the data base to be used. (Note that this must be done before any pits are entered into the Main Window. The selected data base stays in the **.drn** file for each model. New pit, pipe and overflow route types can be added, and existing information can be altered, but for programming reasons it is not possible to remove pipe and pit specifications.)

At this point, you should save the file using the **Save** option in the **File** menu, or the diskette symbol on the Toolbar, naming the file **`Orange1.drn`**. The above processes create a template or shell, containing the base information that will be used to run the model, and the pipe, pit and overflow route types to be referred to when setting up drainage systems. The *DRAINS* **.drn** file can be saved at this stage, to be used later as a starting point for models that use this base information. (The saved file might be named **`Orange template.drn`** or something similar.)

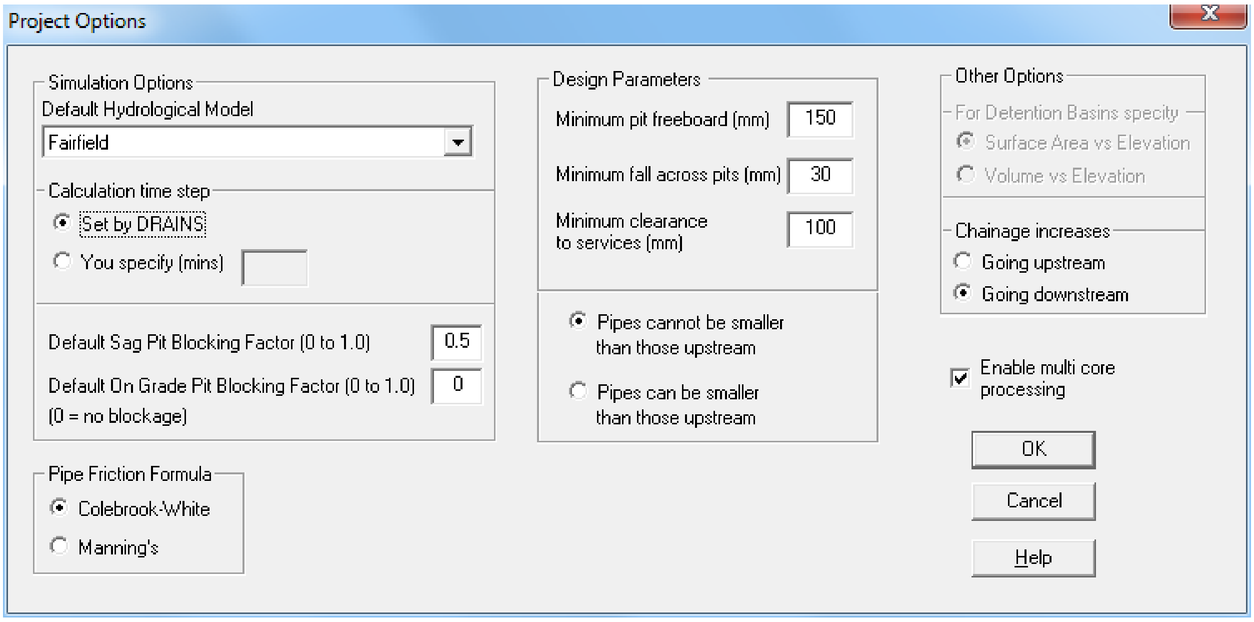


Figure 1.12 The Options Property Sheet

(Note that not all options may appear. Some may not be available with the hardware lock that is being used, and others may be obsolete features in an older *DRAINS* model.)

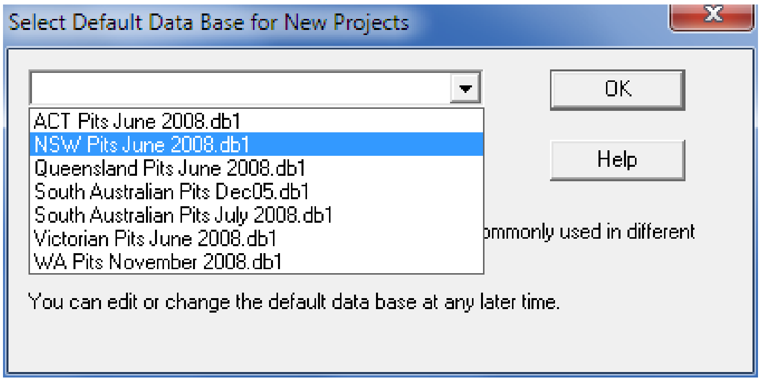


Figure 1.13 Dialog Box Selecting a Data Base for Pipes, Pita and Overflow Routes

(b) Defining the Drainage System

Suppose that the system to be designed is that shown in Figure 1.14.

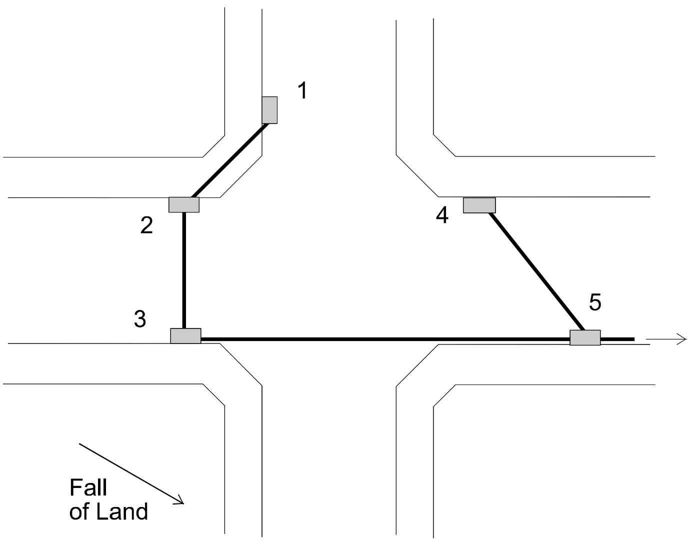
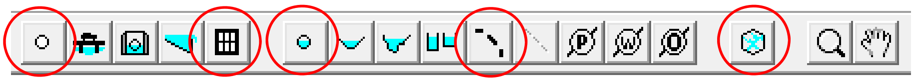


Figure 1.14 A Simple Drainage System

This system can be drawn in the Main Window using five tools from the Toolbar:



As you guide your mouse arrow over the Toolbar items, tool-tips will appear, indicating the purpose of each button. Once you click one of the Toolbar button, the cursor will change to a pencil, which can be used to place that component in the Main Window.

You can use the pit and node tools,  and , to draw five drainage pits and three outlet nodes in the Main Window, as shown in Figure 1.15.

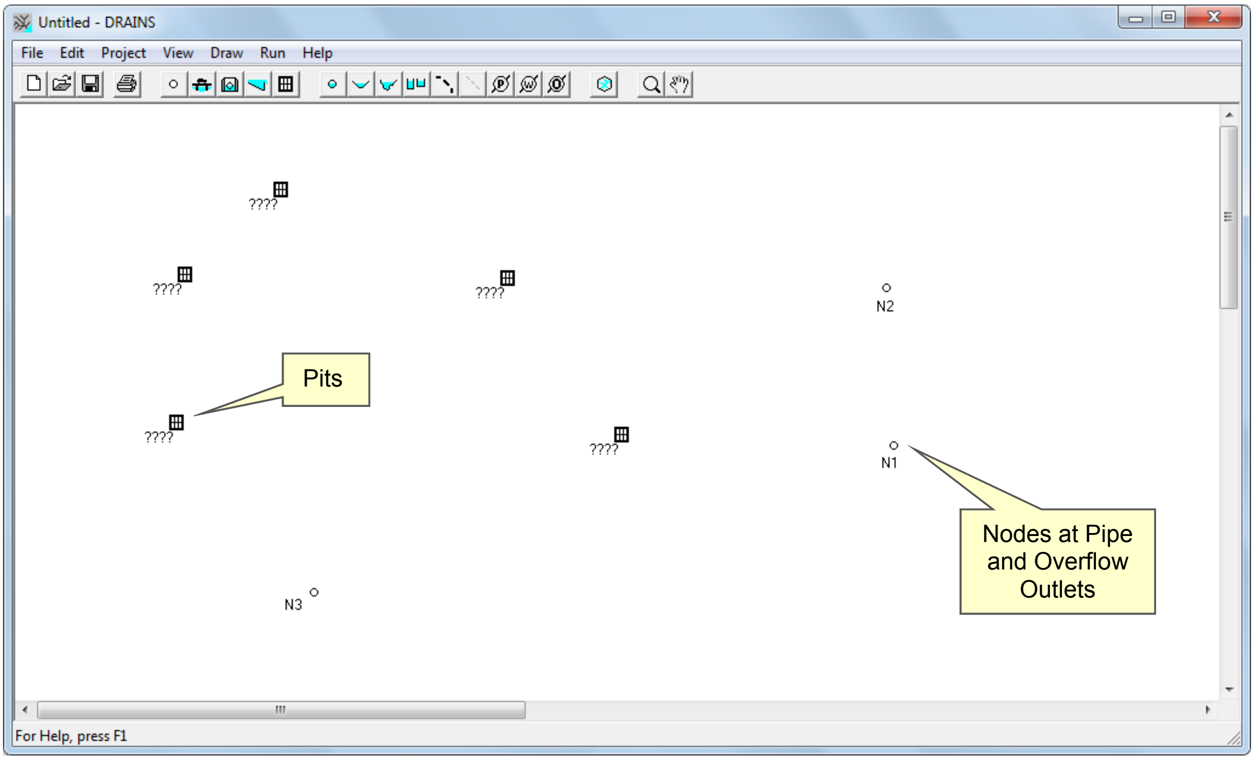
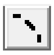
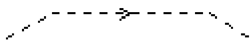


Figure 1.15 Initial Drawing of Drainage System

Note that the overflow paths  can be drawn as a polyline, ., allowing them to be placed to the side in cases where both the pipe and any overflows travel to the same destination. Points along the overflow route are selected using the left mouse button, and the end-point is defined by clicking the right mouse button.

The names of components (mostly given as ???? to start with) can be dragged to more convenient locations. The components themselves can be moved round the screen. You can select a component by clicking it to make 'handles' appear, holding the left mouse button down on it so that horizontal and vertical arrows appear, and then dragging the component to the required location. A pipe or channel can be moved as a single unit by dragging near its centre. Alternatively, their ends can be moved by dragging the handles.

As well as entering data directly onto a blank Main Window, as shown above, you can insert a background from a CAD drawing file, together with a layout of pits and pipes. A drawing file for the current example, **`Orange Base.dxf`**, is shown in Figure 1.17. This can be entered into a *DRAINS* Main Window, after the hydrological, rainfall and options settings have been defined, using the **Import DXF File…** option in the **File** menu, shown in Figure 1.18. This takes you through a set of dialog boxes in which you must nominate layers containing data on the background, pipes (as lines) and pits (as circles), and other information. The first of these is also shown in Figure 1.18.

The pipe system appears as shown in Figure 1.19. This model should be saved as file **`Orange2.drn`**. This view can be enlarged using the magnifying tool or mouse wheel, and you can pan across the model using the pan tool in the toolbar. All pipe lengths can be scaled by setting the length of one pipe. The other components of the system: pits, sub-catchments, overland flow paths and outlets, can then be added.

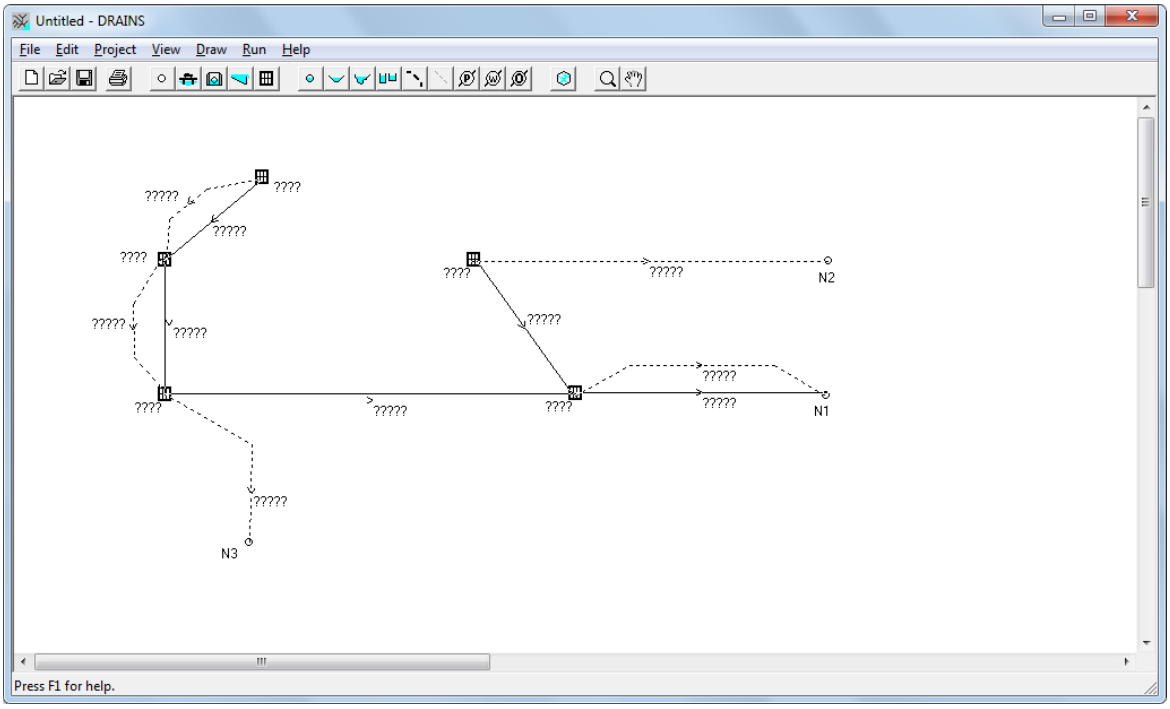


Figure 1.16 More Complete Orange Drainage System Drawing

The background is an image created from vector objects (lines, polylines and arcs) in the nominated layer of the CAD file. It can be switched on and off, and its colour can be changed, using options in the **View** menu.

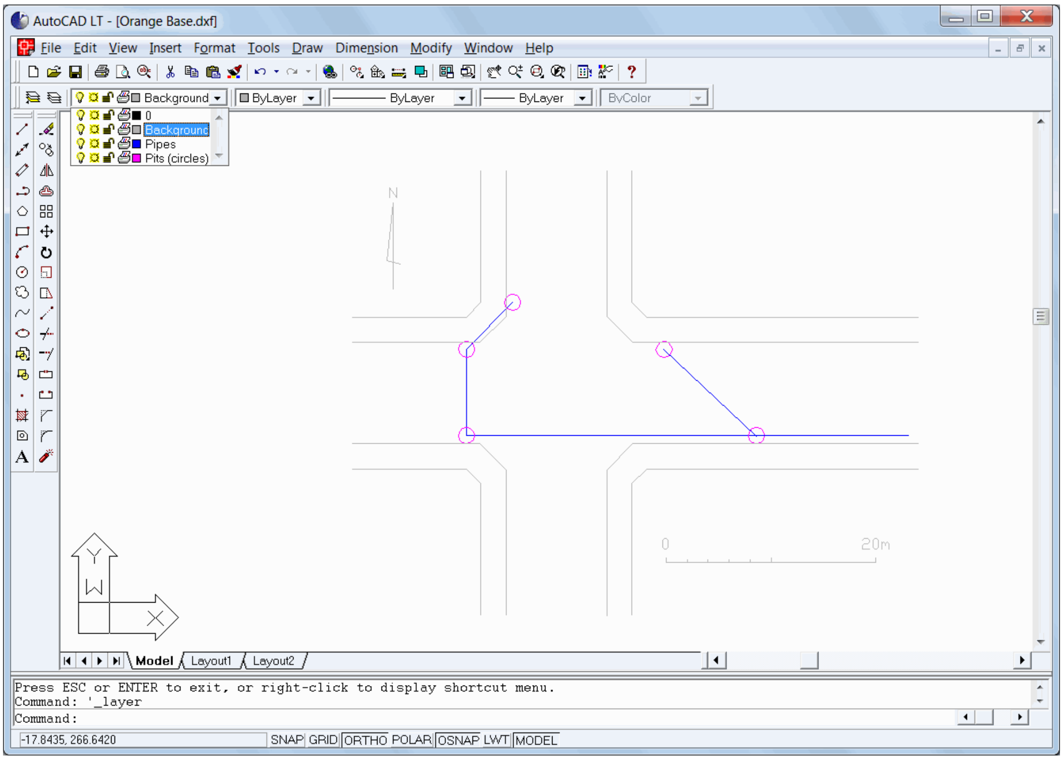


Figure 1.17 CAD Display showing Pipe System Layout and Background

Data for parts of the drainage system can be entered and edited using property sheets that appear when you right-click a component, and select **Edit Data** from the pop-up menu, as shown in Figure 1.20.

The property sheet for Pit 1 is shown in Figure 1.21. This has two pages, the first with pit properties and another optional page for factors to be applied if pit pressure change coefficients are to be calculated using the *Queensland Urban Drainage Manual* (QUDM) charts (refer to Section 3.4.4). These include an aligned/misaligned choice (explained in the *DRAINS* Help system) and the width of the pit wall on which the outlet pipe is located.

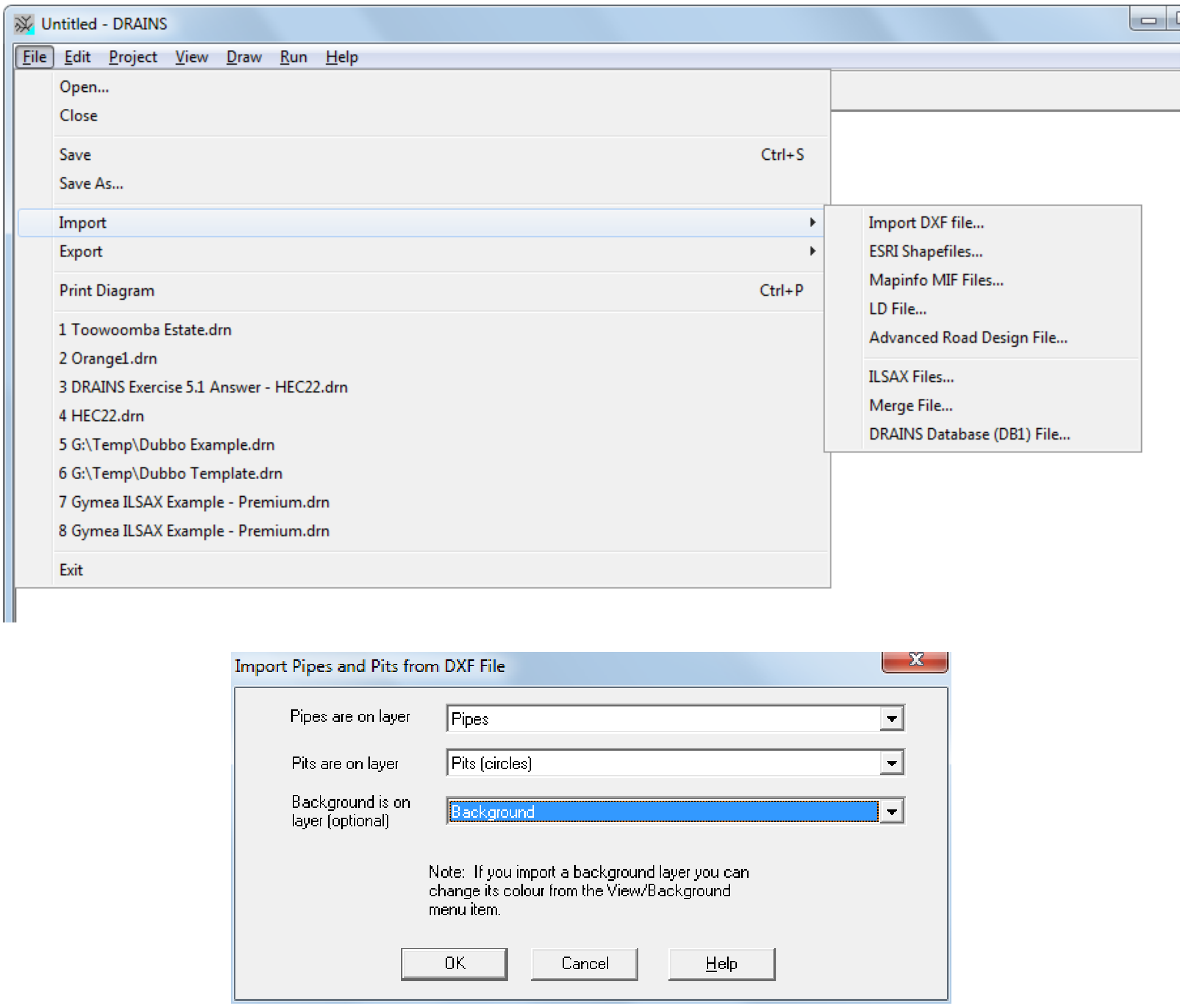


Figure 1.18 Menu and Dialog Box for Nominating CAD Layers

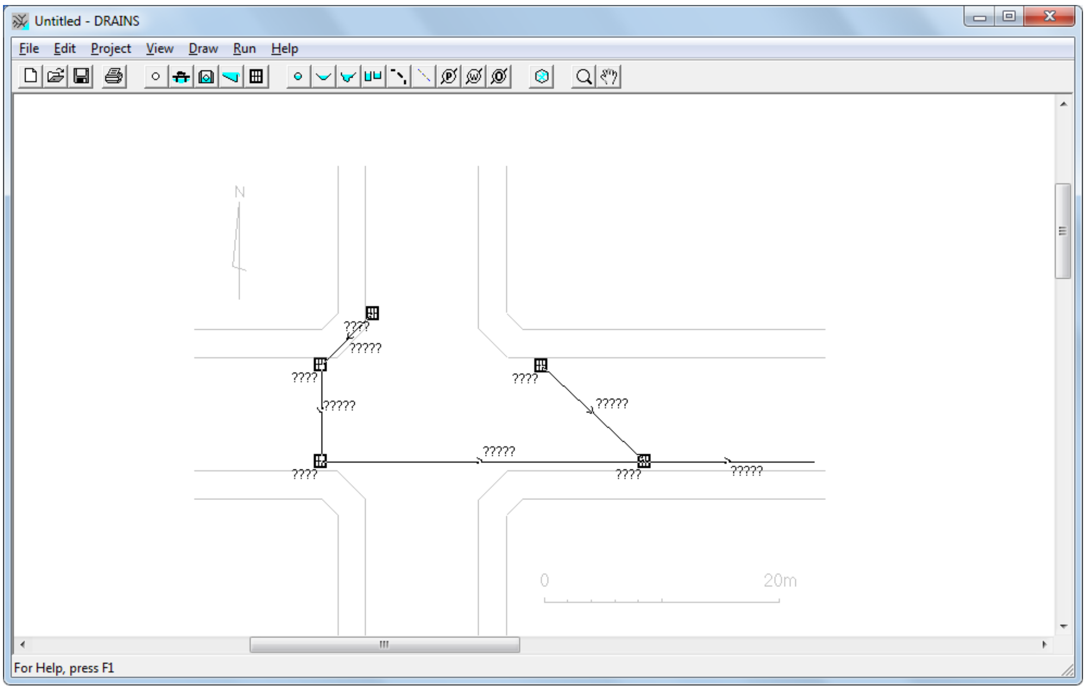


Figure 1.19 Inputted Drainage System from the CAD File

From Figure 1.14 you can see that any overflows from Pit 1 will flow to Pit 2, so that this first pit should be selected as an on-grade pit, on a slope so that no pond will form over the pit. Note how pit types and sizes are selected from a data base of pit types using two drop-down list boxes. (When entering data, you can move from box to box using the **Tab** key on your PC's keyboard.)

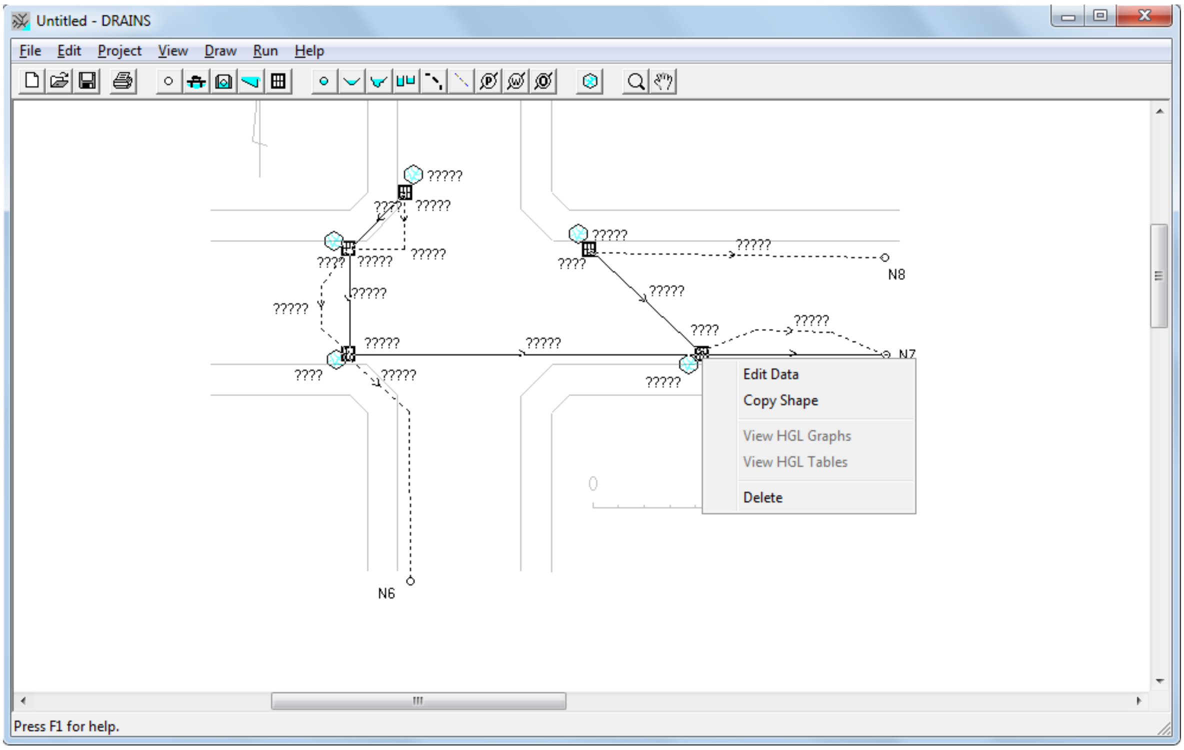


Figure 1.20 Pop-Up (Right Mouse Button) Menu

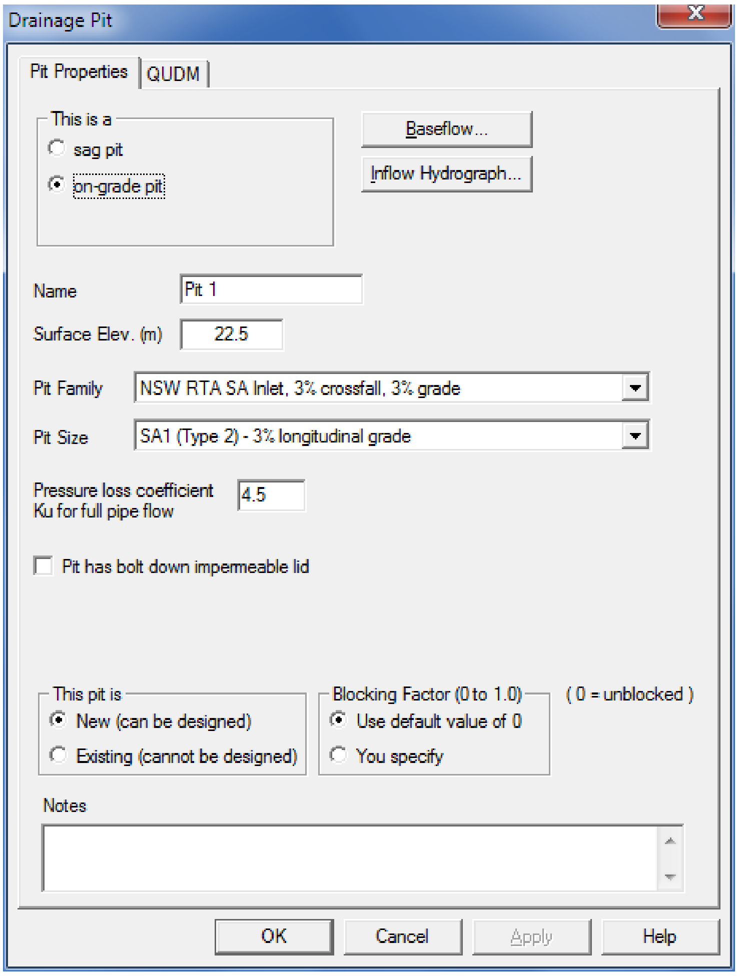


Figure 1.21 A Drainage Pit Property Sheet

The pit pressure change coefficient value of 4.5 is suitable for a pit at the top of a drainage line. You can obtain further information about these factors, which influence the water levels in the pipe system, from the Help system or from Section 0.

After closing the Drainage Pit property sheet, you will find that the pit name has changed and the question marks have disappeared. As data is entered, the allocated names appear in the Main Window. *DRAINS* will not run until all the required data is entered. Even if the data for all components are entered, question marks will remain if the connections between components are incomplete.

Table 1.1 defines the data for the pits in this system. If you are following this example, enter the appropriate values for the five pits. The names of pits can be up to 10 characters long, and those of other components may be slightly larger. Assume all pits to be NSW RTA (Roads and Traffic Authority, now Roads and Maritime Services) SA2 pits, at the slopes shown in the table.

Table 1.1 Pit and Outlet Node Data for the Orange Example

Name	**Pit Type**	**Longit-udinal Slope** (%)	**Ponding Volume** (m^3)	**Ponding Depth** (m)	**Pressure Change Coeff. K_u**	**Surface Elev.** (m)	**Blocking Factor** (0=clear)
Pit 1	On-Grade	5			4.5	22.5	0.0
Pit 2	Sag	1, say	2	0.15	0.5	22.3	0.5
Pit 3	On-Grade	1			1.5	22	0.0
Pit 4	On-Grade	3			4.5	22.1	0.0
Pit 5	On-Grade	1			1	21.7	0.0
Outlet 1	Node					21	
Outlet 2	Node					21.5	
Outlet 3	Node					21	

Pit 2 is a sag pit, located in a hollow in which stormwater can form a pond over the pit. For this type of pit, there is an additional page on the property sheet, labelled Pond Properties, where extra information has to be provided - an allowable ponding depth and a maximum ponded volume, here taken to be 0.15 m and 2 m^3.

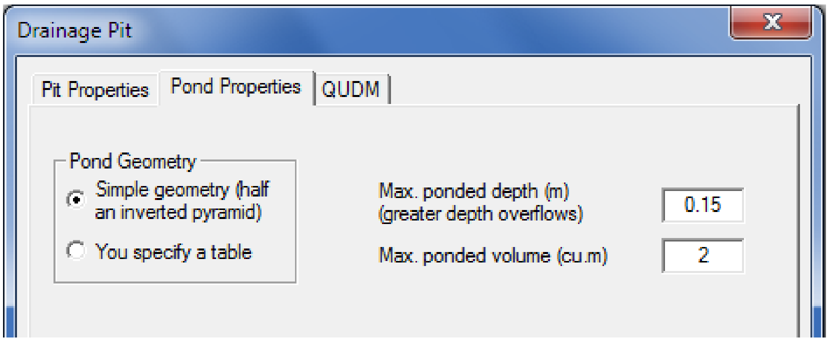


Figure 1.22 A Drainage Pit Property Sheet

Next, you can enter the sub-catchments,  as shown in Figure 1.20. The sub-catchment symbol should no be placed over a pit. If this is done, it will snap to the top right corner of a pit, and can then be moved to another location around the pit if you wish. The data for sub-catchments is entered into their property sheets, which are opened from a pop-up menu in the same way as for pits. The simplest form of the property sheet is shown in Figure 1.23.

The sub-catchment draining to each pit is divided into three types of land-use:

- paved areas (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system), and
- grassed areas (pervious areas).

A time of entry is assigned to each land-use. This is the time that it takes for stormwater to flow from the furthest boundary of each type to the point nearest to the pit. The supplementary area drains onto the pervious area. If the grassed area does not extend to the pit, a lag time is specified to account for the time taken for this grassed area runoff to pass over the section of paved area near the pit. Times can be calculated using the equations and guidelines presented in Section 5.3.2(d).

The parameters for all sub-catchments are presented in Table 1.2. After entering values for Catchment Cat 1, enter parameters for the four other sub-catchments. The displayed names of all should change from '?????' to the names you provide - if not, check that the symbol for each sub-catchment touches the symbol for the related pit.

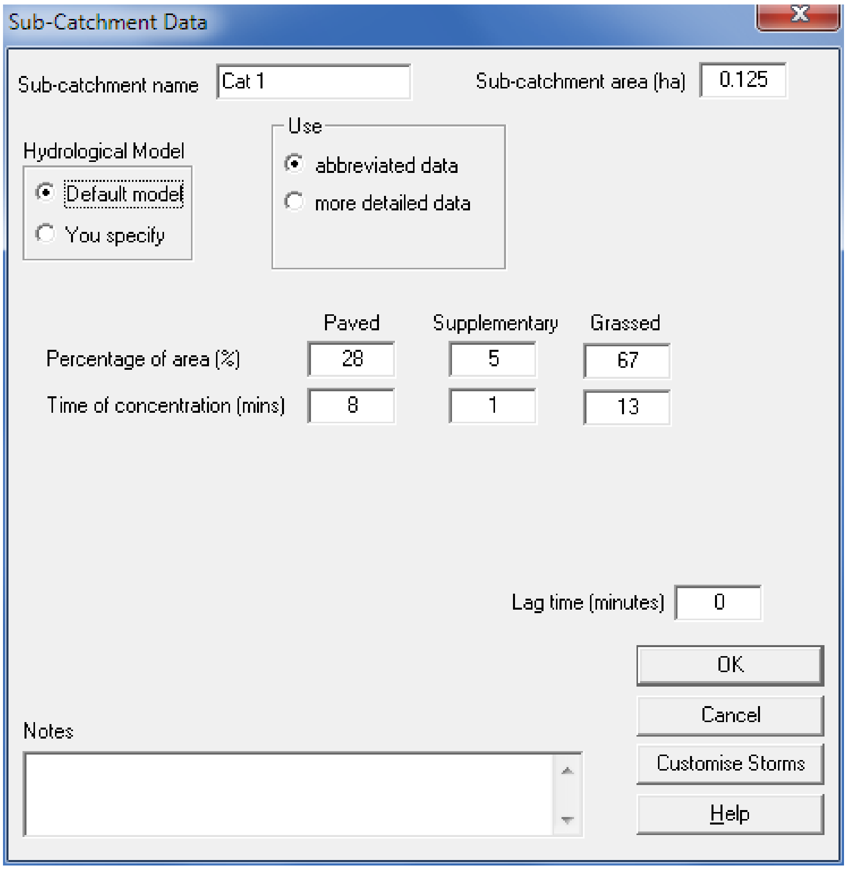


Figure 1.23 The Sub-Catchment Data Property Sheet

Table 1.2 Sub-Catchment Data for Orange Example

Name	**Pit or Node**	**Total Area** (ha)	**Paved Area** (%)	**Suppl. Area** (%)	**Grassed Area** (%)	**Paved Time** (mins.)	**Suppl. Time** (mins.)	**Grassed Time** (mins.)	**Lag Time** (mins.)
Cat 1	Pit 1	0.125	28	5	67	8	1	13	0
Cat 2	Pit 2	0.231	33	5	62	9	1	15	0
Cat 3	Pit 3	0.025	90	0	10	3	0	4	0
Cat 4	Pit 4	0.35	75	5	20	9	1	15	0
Cat 5	Pit 5	0.02	90	0	10	2	0	3	0

Pipe data is entered by right-clicking on pipes to open their property sheets. You need to click on the object and not on its name, as the latter will open the dialog box (illustrated later in Figure 3.19) that defines the information shown in the Main Window. Figure 1.24 shows the sheet for the first pipe.

It is not necessary to specify invert levels or slopes because *DRAINS* will calculate these during the design. You must, however, specify the pipe name, length and type, selecting the type from a list box. (If you have inserted a background, pipe lengths can be automatically scaled after the first length is entered.) You can also take the lengths of the remaining pipes from Table 1.3.

When you close the property sheet, you will find that the pipe name is prefixed with '??', indicating that the data are still incomplete.

Overflow routes are the next components to be defined. You must define a name and an estimated time of flow, as shown in Figure 1.25, and you must also define overflow route cross-sections from the overflow route data base, with slopes and percentages of downstream sub-catchments, as shown in Figure 1.26.

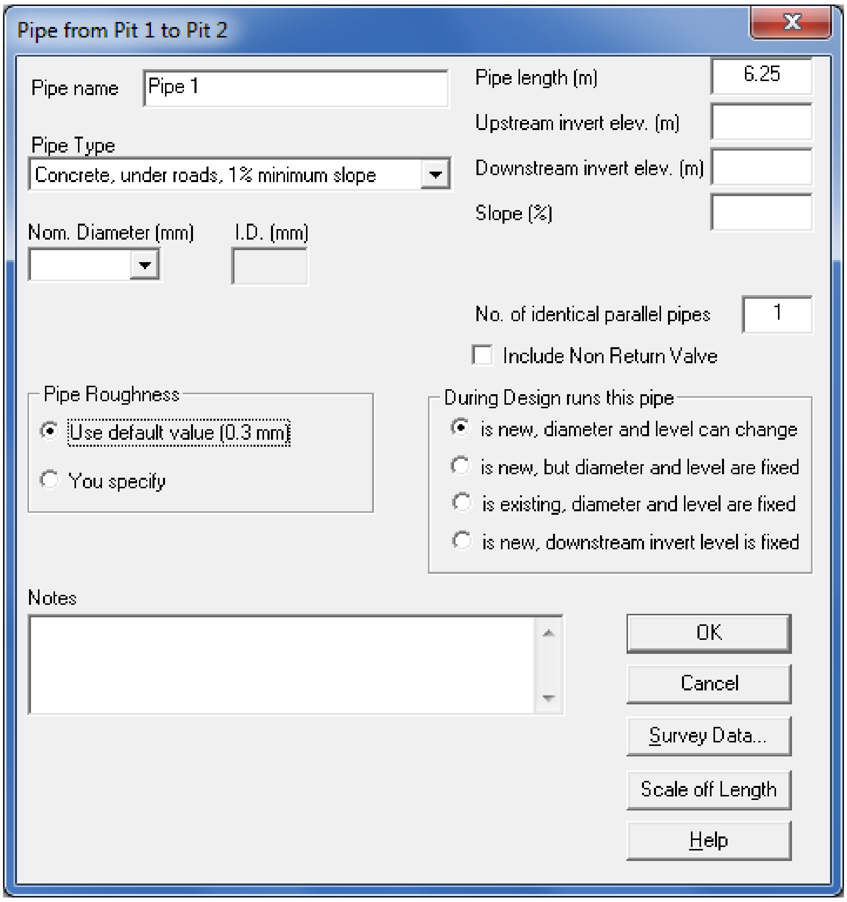


Figure 1.24 The Pipe Property Sheet – Page 1

Table 1.3 Pipe Data for Orange Example

Name	**From**	**To**	**Length** (m)
Pipe 1	Pit 1	Pit 2	6.25
Pipe 2	Pit 2	Pit 3	8.19
Pipe 3	Pit 3	Pit 5	27.6
Pipe 4	Pit 4	Pit 5	12.03
Pipe 5	Pit 5	Outlet	14.05

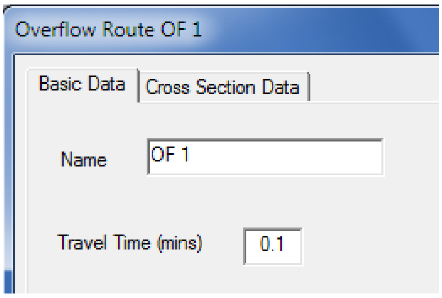


Figure 1.25 The Overflow Route Property Sheet - Page 1 (Top Portion)

(Note that Figure 1.25 may include additional data entry boxes if the storage routing or premium hydraulic model options are available. Only the information shown above is required in the Orange example.) The overflow route information for this example is shown in Table 1.4.

The percentages of downstream areas are used to define flow characteristics along the overflow route, as explained in Section 2.3.6.

Finally, the outlet names and levels must be defined. Here it is assumed that the main outlet operates as a free outfall. The tailwater level for the pipe system will be the higher of the normal and critical depths for the outlet pipe, unless this is running full. Outlet surface levels are specified in Table 1.1.

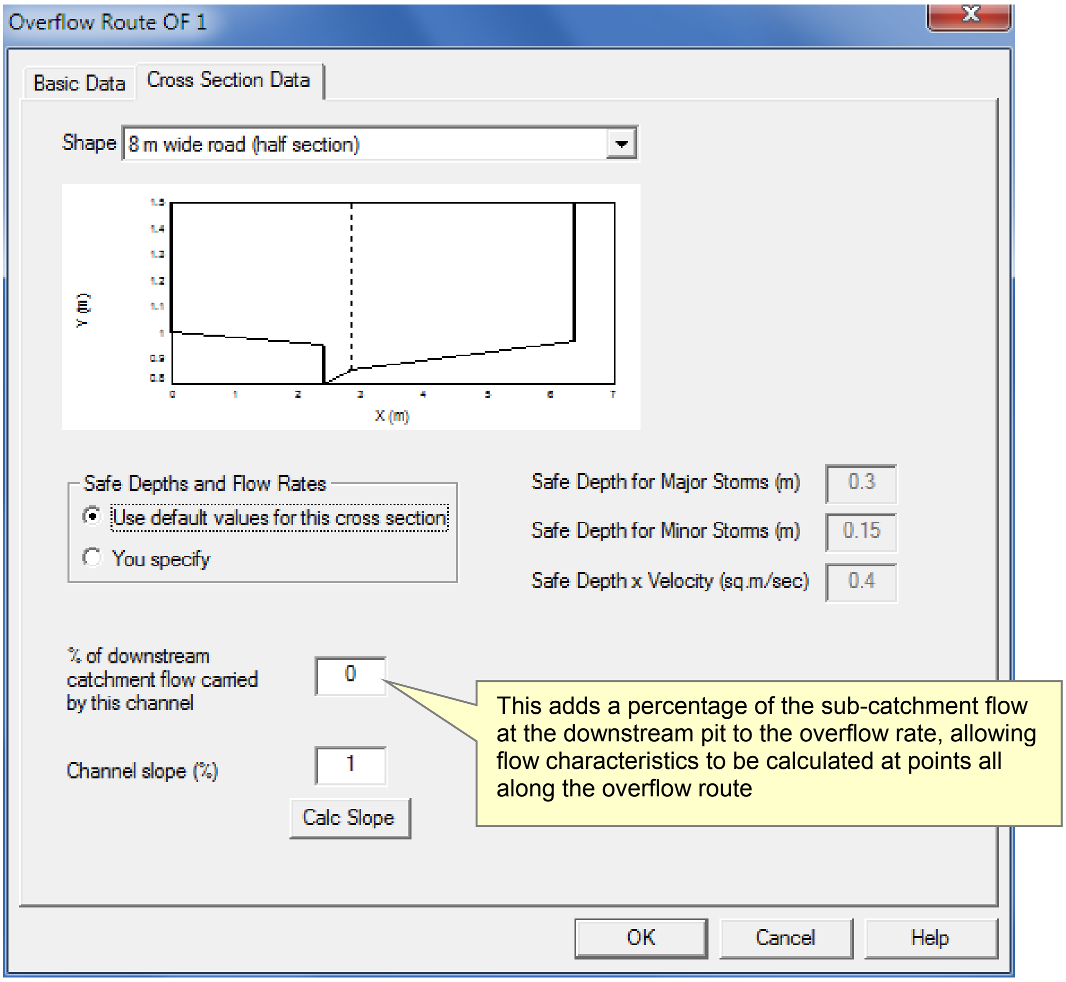


Figure 1.26 The Overflow Route Property Sheet - Page 2

Table 1.4 Overflow Data for Orange Example

Name	**From**	**To**	**Travel Time** (minutes)	**% of D/S Catchment**	**Flow Path Slope** (%)
OF 1	Pit 1	Pit 2	0.1	0	4
OF 2	Pit 2	Pit 3	0.1	0	3
OF 3	Pit 3	Outlet 3	1	0	3
OF 4	Pit 4	Outlet 2	1	0	1
OF 5	Pit 5	Outlet 1	1	0	1

As these changes are made, you should periodically save the file and tidy it up so that it looks like the arrangement in Figure 1.28. If you have **Property Balloons** switched on in the **View** menu, details of the data for various components can be seen without opening property sheets.

(a) Running the Program

You can now run the program in Design mode from the **Run** menu, shown in Figure 1.27.

After a Design run, the message in Figure 1.29 appears advising that the process is complete and that you should run an analysis with minor or major storms to assess the results. You can do this my choosing the **Analyse minor storms** and **Analyse major storms** options. The standard hydraulic model is available in all *DRAINS* model. The optional, premium model requires more detailed information on overflow routes, in order to model them with unsteady flow hydraulics.

When performing an analysis, *DRAINS* is likely to display the message shown in Figure 1.30.

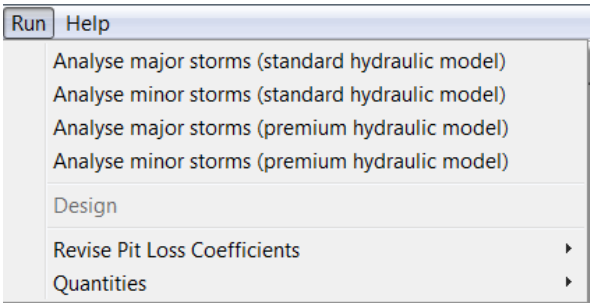


Figure 1.27 Run Options

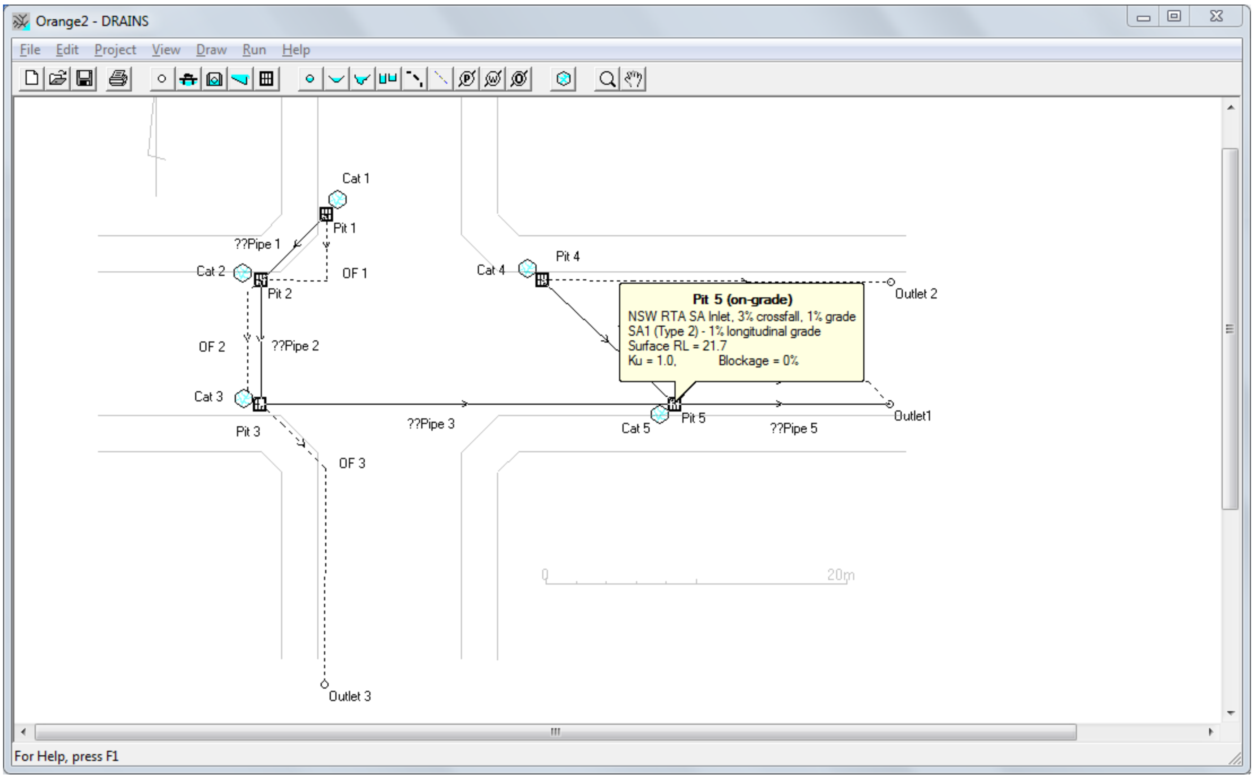


Figure 1.28 Orange Drainage System Ready to Run (with Property Balloon shown)

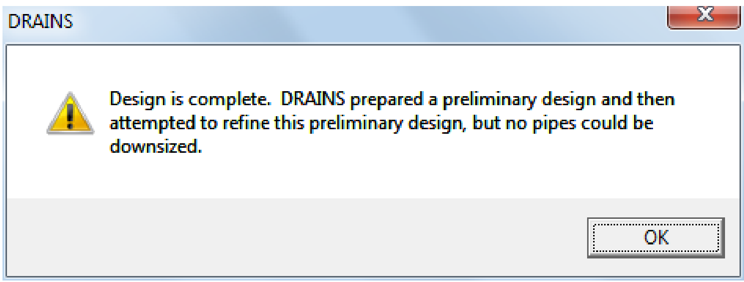


Figure 1.29 Run Completion Message

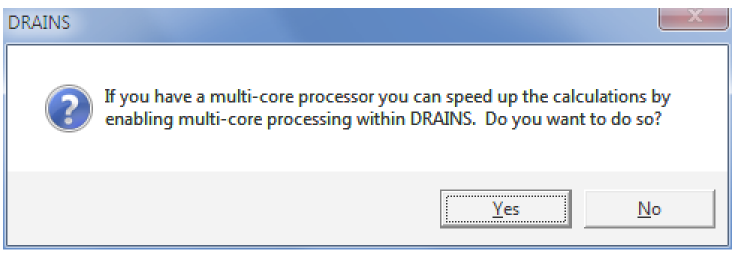


Figure 1.30 Multi Core Processing Query

If you agree, *DRAINS* will display the Project Options property sheet (Figure 1.12) in which you can click the box titled **Enable multi core processing** to reduce the processing time. Whatever choice is made, the analysis run proceeds, and a report is displayed after it finishes, as shown in Figure 1.31.

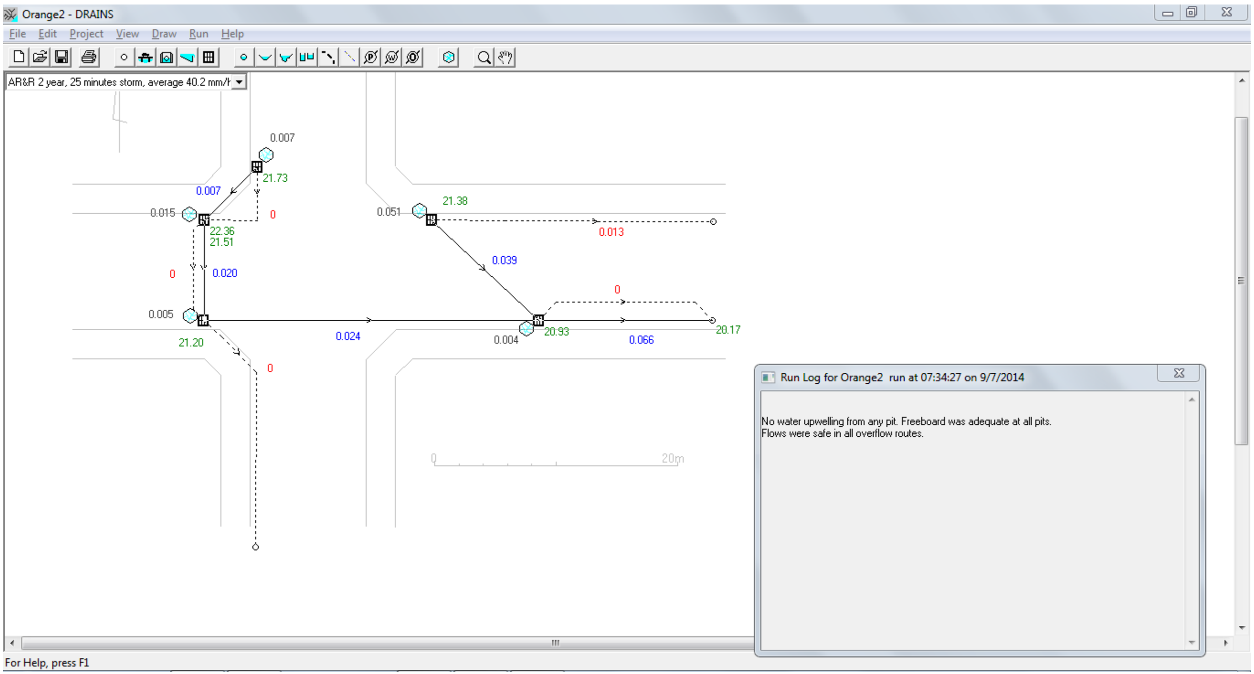


Figure 1.31 The Result of a Design Run and Minor Storm Analysis

After you close this window you will see that the names of components have changed to coloured numbers as follows:

- the **black** numbers are the maximum flowrates from the sub-catchments, in m^3/s,
- the **blue** numbers are the greatest flowrates in each pipe, in m^3/s,
- the **red** numbers are the greatest overflows from pits, in m^3/s, in the standard hydraulics model, or the flowrates at the centre of an overflow path in the premium hydraulic model (which will include any flows from the downstream sub-catchment),
- the **green** numbers are the highest levels reached by the hydraulic grade lines (HGLs) throughout the pipe system, in m elevation, defining the highest water levels during the 2 year ARI, 25 minute storm event considered. (At sag pits, the highest surface ponding level is also shown.)

Since it calculates conditions at a number of time intervals, *DRAINS* produces hydrographs or time series of runoff flowrates from the rainfall hyetographs. It is possible to view what happens at all times during the storm event, as shown in Figure 1.32.

(a) Reviewing Results

You can now inspect the results and check the pipe inverts and sizes determined by *DRAINS*. There are a number of ways of doing this, the most comprehensive being the transfer of information to a spreadsheet using options within the **Edit** menu. The data spreadsheet for the Orange Example is shown in Figure 1.33.

Results of particular runs of *DRAINS* can also be exported to worksheets using the **Edit** menu, as shown in Figure 1.34. These can be, for example, minor and major storm results from design procedures.

The major/minor system is usually employed in Australian drainage design. Pipes are sized to carry flows of a minor ARI, from 2 to 10 years, and a check is made to ensure the safe working of the system during a major storm event, with an ARI of about 100 years.

So far, *DRAINS* has performed the design, determining pipe sizes and invert levels. You can now also perform an analysis using the 100 year ARI, 25 minute rainfall pattern. Simply run **Analyse major storms** from the **Run** menu to produce the results shown in Figure 1.35.

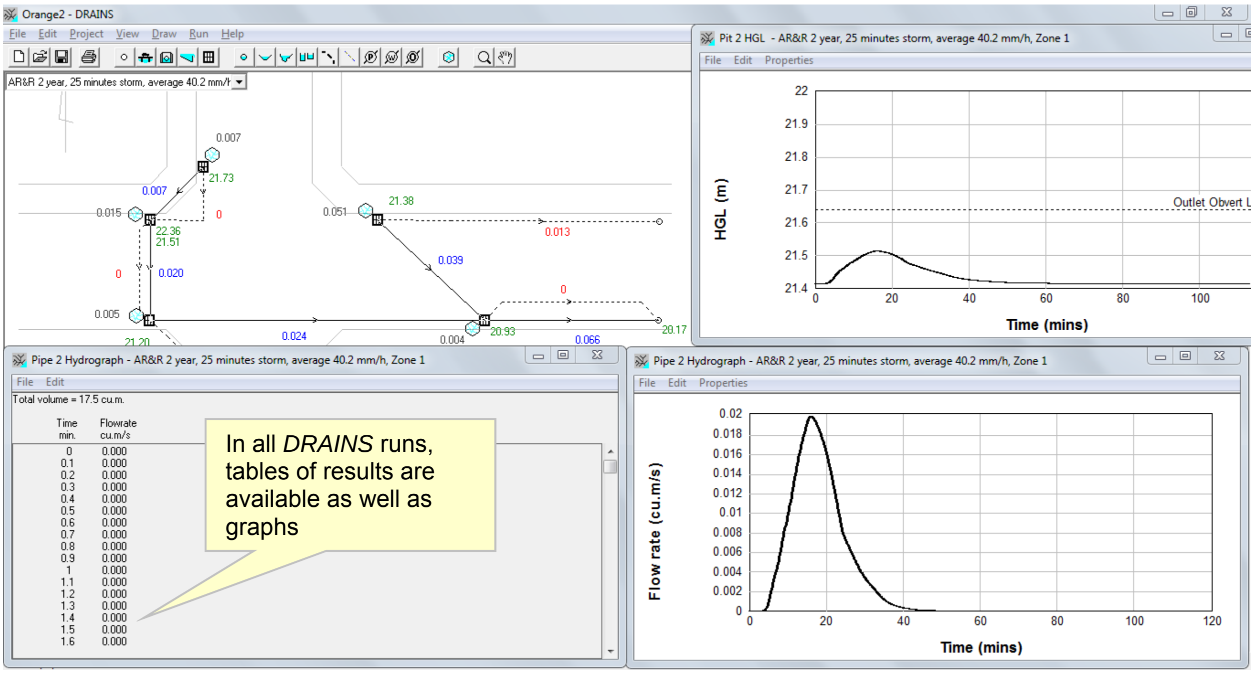


Figure 1.32 Hydrograph and Hydraulic Grade Line Results for a Minor Storm

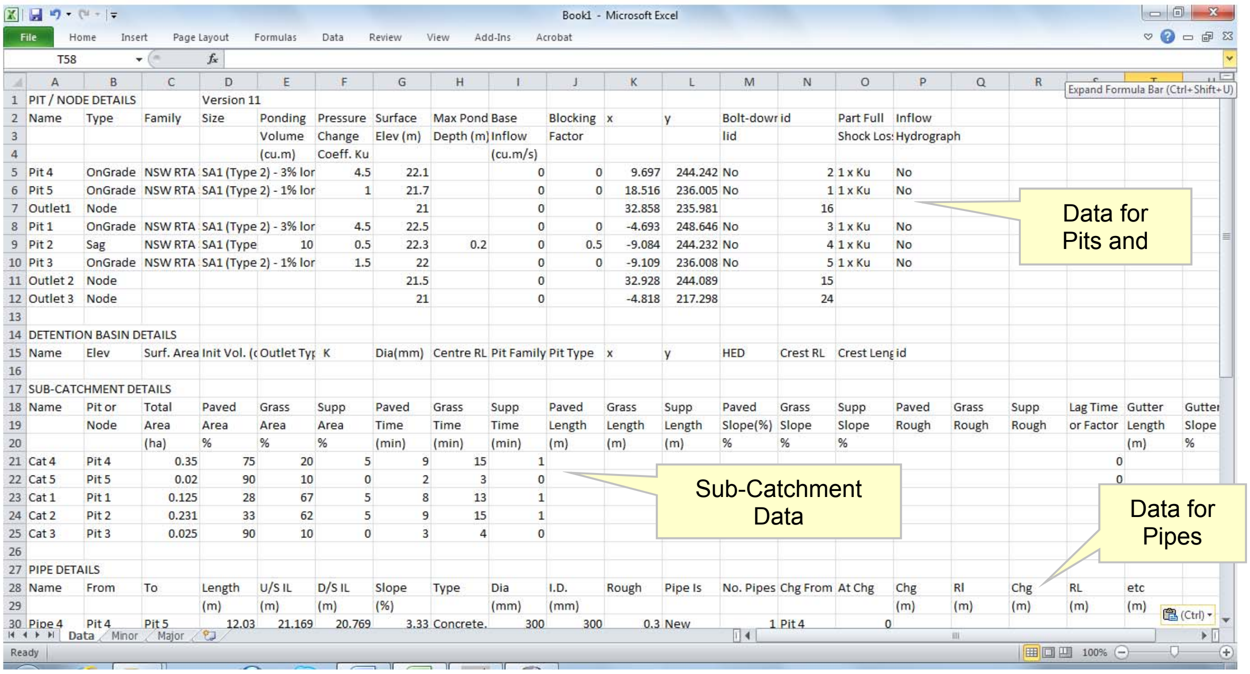


Figure 1.33 Spreadsheet Output for Data

The flowrates are now larger and some overflows occurring. These can be inspected using the Cross Section Data page of the Overflow Route property sheet, as shown in Figure 1.36. With the standard hydraulic model, these characteristics are based on normal depth calculations (The premium hydraulic model calculations apply a more rigorous and accurate unsteady flow analysis.)

The suitability of the overflows during minor or major storms can be assessed and the system enlarged if flow characteristics such as widths exceed acceptable limits.

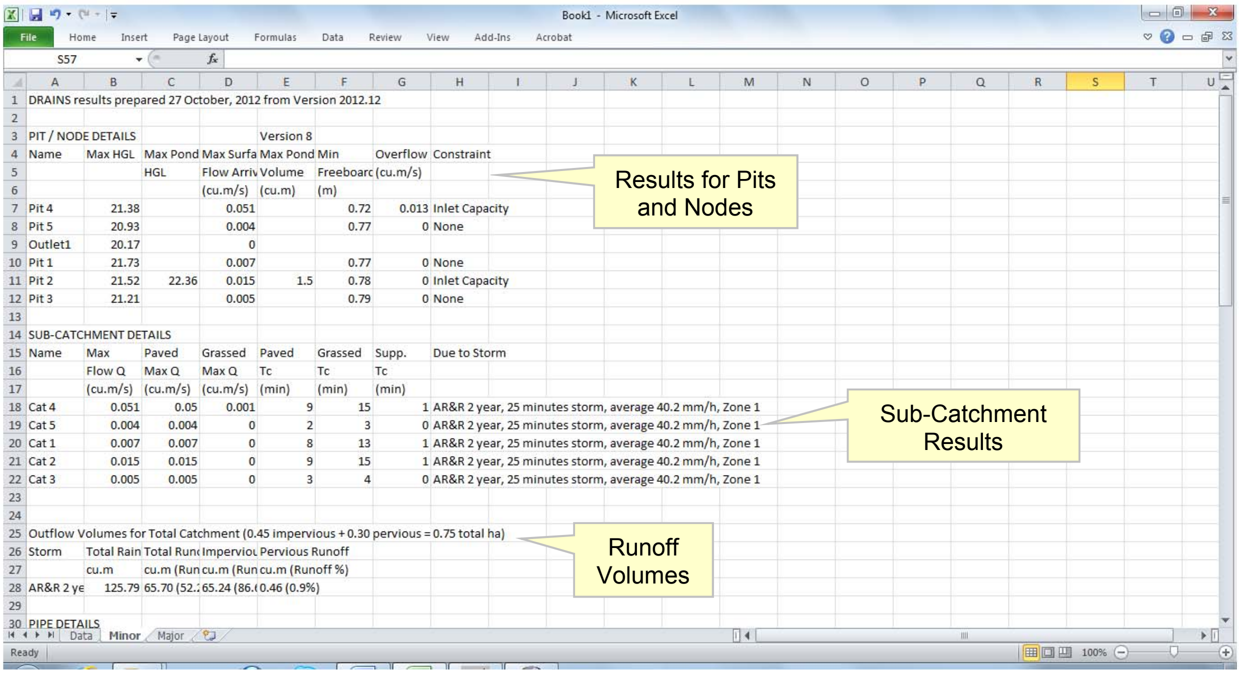


Figure 1.34 Spreadsheet Output for Minor Storm Results

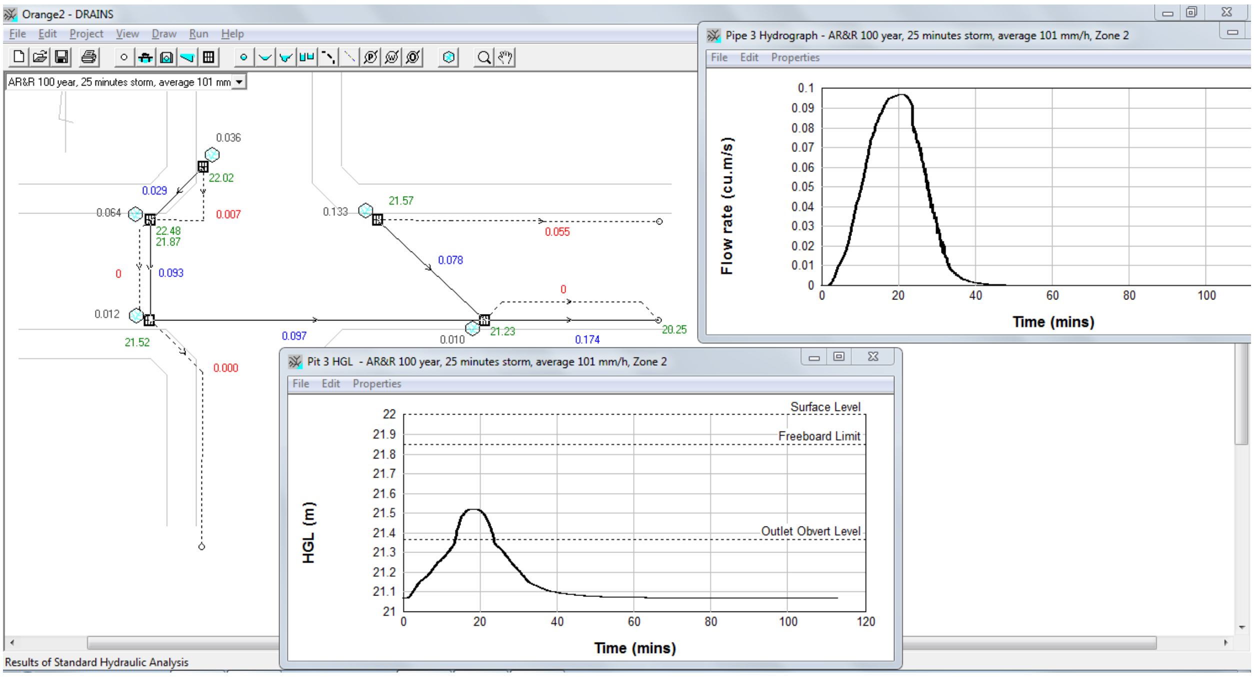


Figure 1.35 Analysis Run Results for a Major Storm

(a) Saving Data and Results

This last step involves the storage of results. The input data is all stored in the *DRAINS* data file **`Orange2.drn`**. There is plenty of opportunity to make comments, in the spaces provided in the property sheets for individual components, and in a **Description …** option in the **Project** menu.

The spreadsheet results can also be stored, and, as is detailed in Chapter 3, it is also possible to transfer the results via a DXF file to drawing programs that can print plans and longitudinal cross-sections of pipe systems. Additional results from analysis runs are shown in Figure 1.37

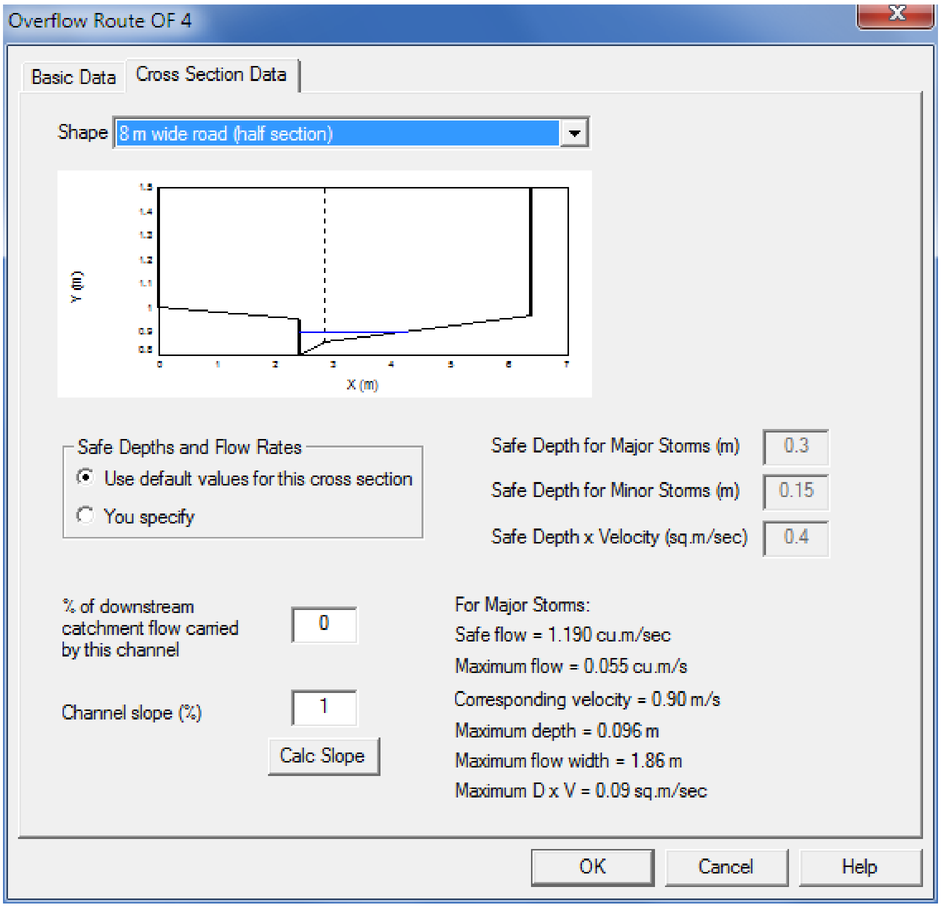


Figure 1.36 Overflow Route Property Sheet, showing Flow Characteristics

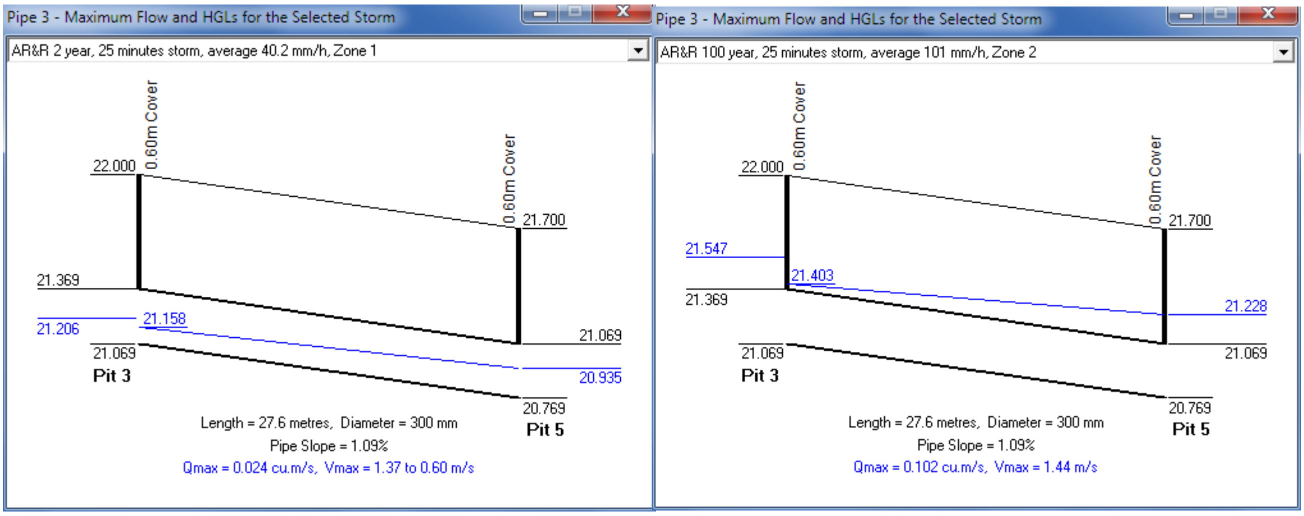


Figure 1.37 Long-Section Display for a Pipe showing 2 Year and 100 Year ARI Results

The pipe design is performed on the basis of the allowable flow along the overflow route. The method determines this flowrate, taking into account the flows from of the sub-catchment immediately downstream of each pit. It then works backwards to define a set of pit inlets and pipe sizes that will limit overland flows to safe levels in both minor and major storms. Safety requirements are defined in terms of flow depths and velocity-depth products in the Overflow Route Data Base, as shown in Figure 1.26.

1.2.2 Running the Rational Method and Extended Rational Method Models

To illustrate the rational method procedure, the same Orange system can be modelled using a rational method hydrological model in the file named `Orange2Rat.drn`. You can run this if your hardware lock is enabled to run the rational method, or if you are using the DEMO version.
This file can be created in the same way as the ILSAX model, but it is also possible to adapt the model to run with the rational method procedures. Only three of the property sheets for data entry differ from those

for the ILSAX hydrological model. In the setting up of project options, the Hydrological Model for a rational method model called from the dialog box in Figure 1.5 takes the form shown in Figure 1.38.

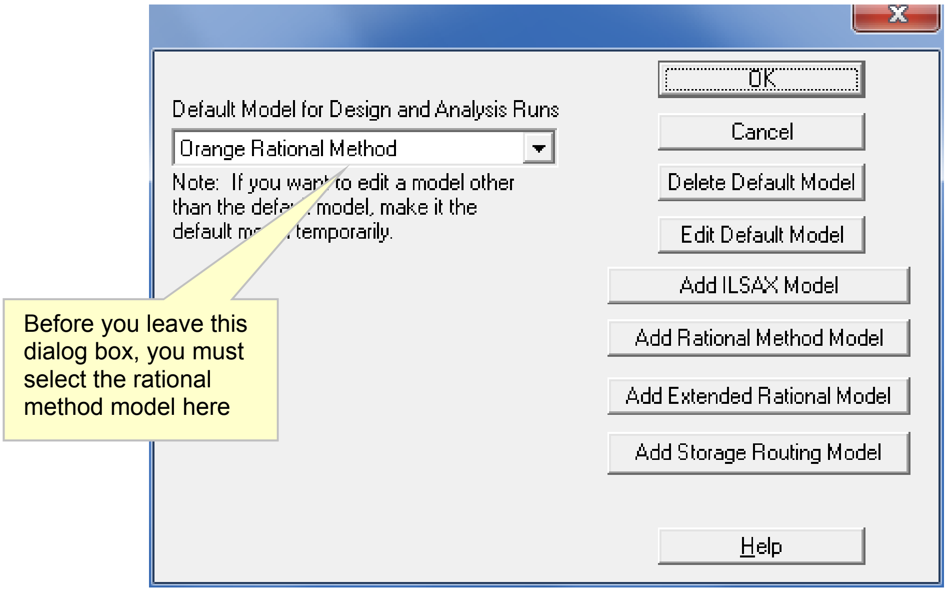


Figure 1.38 Hydrological Model Property Sheet for the Rational Method

There are three choices on the type of rational method procedure to be used. The version from *Australian Rainfall and Runoff*, 1987 is selected, as shown in Figure 1.39.

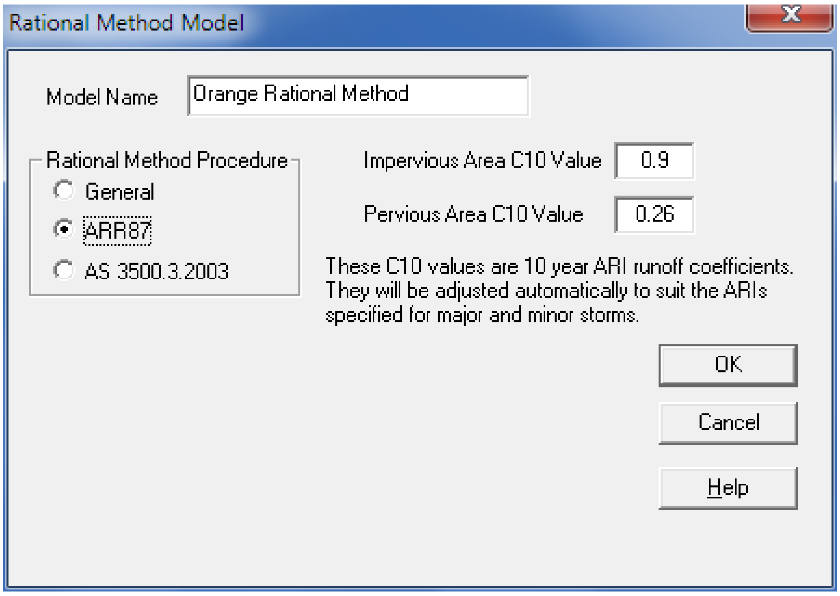


Figure 1.39 Rational Method Model Specification

The 10 year ARI runoff coefficient C_{10} for the pervious area is set at 0.26, based on a 10 year ARI, 1 hour rainfall intensity, ${}^{10}I_1$ of 37.2 mm/h entered into Equation 14.12 in *Australian Rainfall and Runoff*, 1987:

$$C_{10} = 0.1 + 0.0133 \times ({}^{10}I_1 - 25).$$

The selection of a rational method hydrological model acts as a switch that affects other parts of the program. When the **Rainfall Data…** option is selected in the **Project** menu, the property sheet that appears (Figure 1.40) is different to that shown previously in Figure 1.8.

Into this sheet you can enter the minor and major ARIs you require and the corresponding design rainfall intensities for durations of 6 minutes, 1 hour, 12 hours and 72 hours. This information is available from *Australian Rainfall and Runoff*, 1987, the Bureau of Meteorology's CDIRS procedure, or from councils' drainage design manuals or codes. Updated information soon will be available from the Bureau of Meteorology's website, www.bom.gov.au.

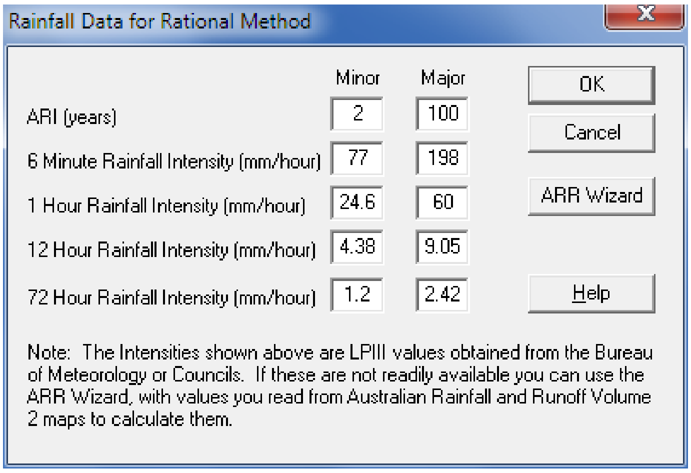


Figure 1.40 The 'Rainfall Data for Rational Method' Property Sheet

The ARR Wizard button allows this information to be obtained from nine factors that can be found from Volume 2 of *Australian Rainfall and Runoff*, 1987. These are entered in the property sheet shown in Figure 1.41. The intensities are calculated from this information, and are used to establish the full intensity-frequency-drainage relationship used by *DRAINS* for rational method calculations.

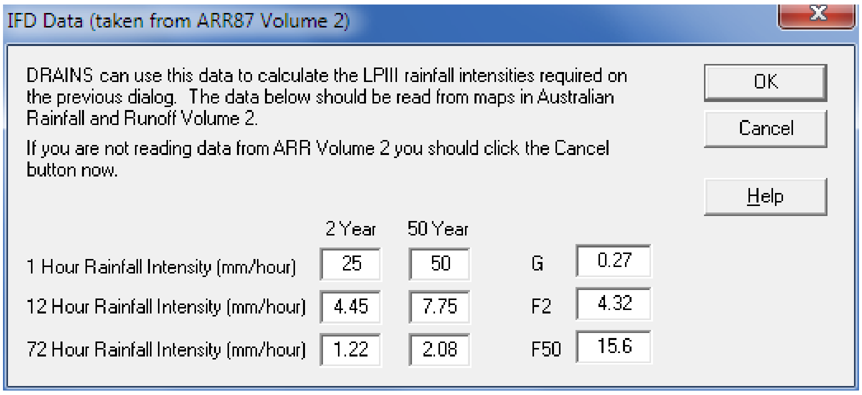


Figure 1.41 Factors from *Australian Rainfall and Runoff*, 1987, Volume 2

The remaining property sheet that is different is for sub-catchments, shown in Figure 1.42. The rational method does not distinguish between directly-connected and non-directly-connected impervious areas. The paved and supplementary area percentages are added to produce a percentage impervious, and the ILSAX model grassed area becomes the pervious area. The data that needs to be entered for sub-catchments is presented in Table 1.5, and run results are shown in Figure 1.43. (The flowrates differ from those provided by the ILSAX model in Figure 1.31. The results provided by the alternative models are discussed in Section A.4.4 of the Appendix.)

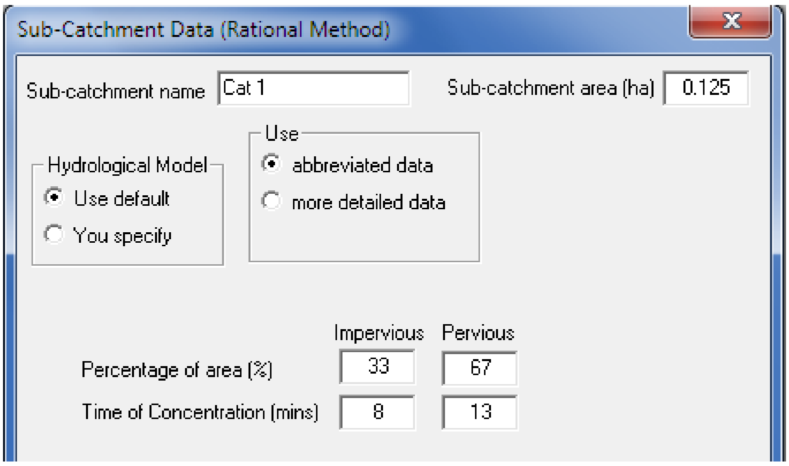


Figure 1.42 Sub-Catchment Data Property Sheet with Rational Method

Table 1.5 Rational Method Sub-Catchments

Name	Pit or Node	Total Area (ha)	Roofed (%)	Impervious (%)	Pervious (%)	Impervious t_c (mins.)	Pervious t_c (mins.)	Impervious C_{10}	Pervious C_{10}
Cat 1	Pit 1	0.125	0	33	67	8	13	0.9	0.26
Cat 2	Pit 2	0.231	0	38	62	9	15	0.9	0.26
Cat 3	Pit 4	0.025	0	90	10	3	4	0.9	0.26
Cat 5	Pit 5	0.02	0	90	10	2	3	0.9	0.26
Cat 4	Pit 4	0.35	0	80	20	9	15	0.9	0.26

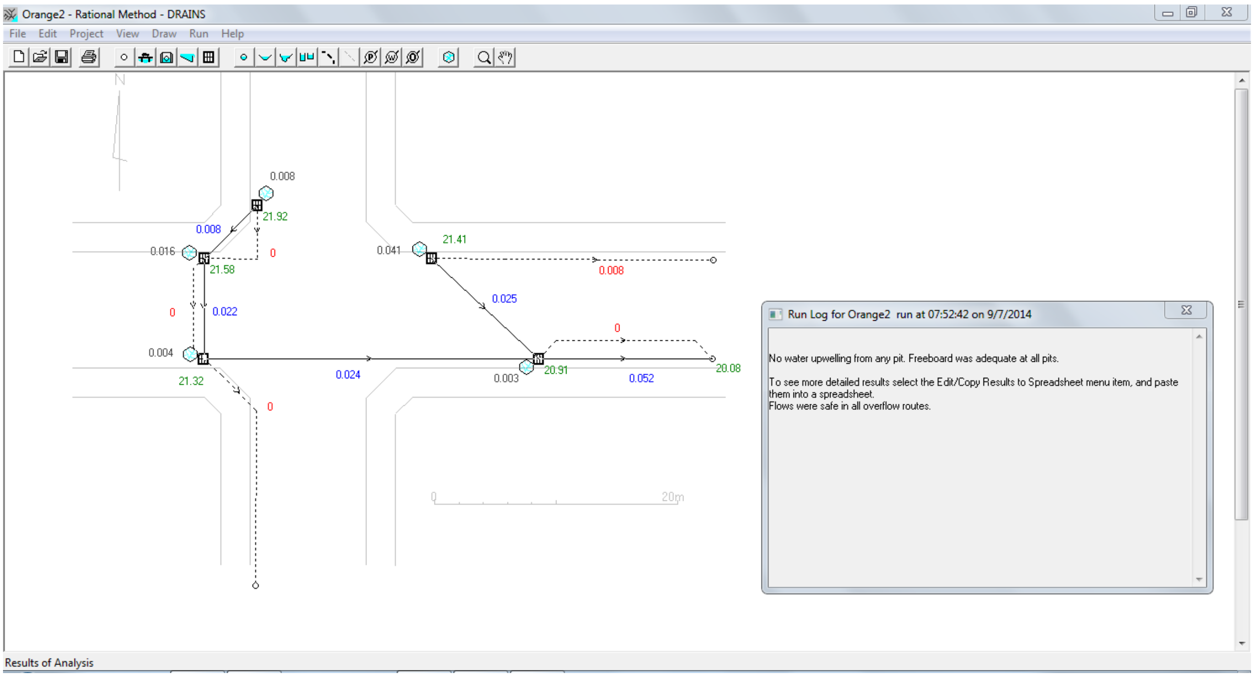


Figure 1.43 Results of Rational Method Design Run

DRAINS also provides an Extended Rational Method (ERM) model, using many of the assumptions in the *Australian Rainfall and Runoff* version of the rational method. This can use design storm patterns like those employed by the ILSAX hydrological model. The method is described fully in Section 5.3.5.

1.2.3 Running the Premium Hydraulic Model

The unsteady flow model used in the standard hydraulic model makes allowance for the storage effects of flows along pipes and open channels. The premium model extends this to overflow routes, allowing accurate determination of water levels and flow characteristics during large storm events.

Some additional data is required for premium hydraulic model calculations. This is revealed when you attempt to run an existing model such as the `Orange2.drn` with premium model calculations, using the second or third options in the Run menu in Figure 1.27. For each overflow route, a route length must be specified in addition to the travel time in the Overflow Route property sheet, as shown in Figure 1.44.

Figure 1.44 also shows the entry of required invert levels at the beginning and end of the overflow route. You can enter this yourself, or allow *DRAINS* to provide values at the start of a run, checking these later. The remaining issue is to specify outlet controls at sag pits. These are usually weirs representing barriers such as road crowns or centrelines. Only one sag pit occurs in the `Orange2 - premium. Drn` model, and the control will be modelled as a parabolic weir, as shown in Figure 1.45.

In Step (b) of the process of setting up a *DRAINS* model, the other data, for pits, pipes overflow routes and nodes, is entered in the same way as for runs using the ILSAX hydrological model.

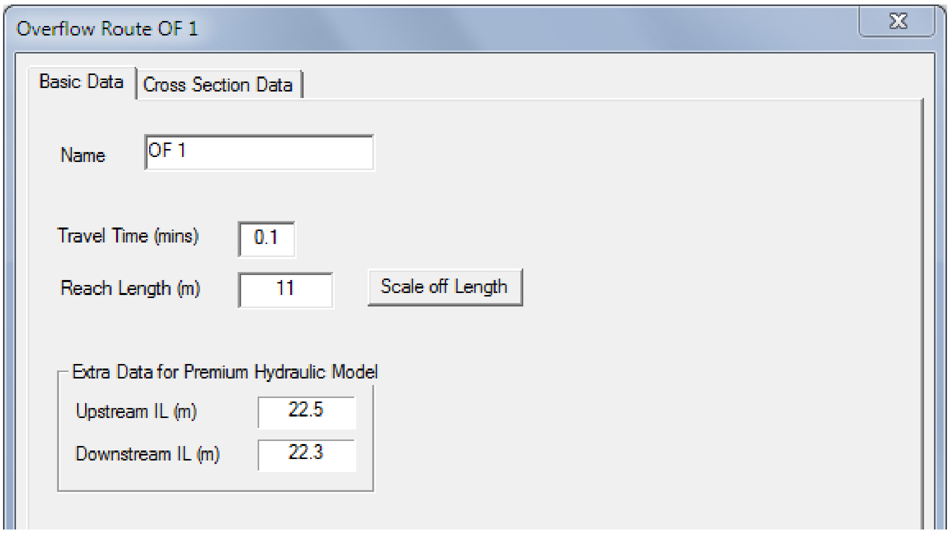


Figure 1.44 Overflow Route Property Sheet for Premium Hydraulic Model Calculations

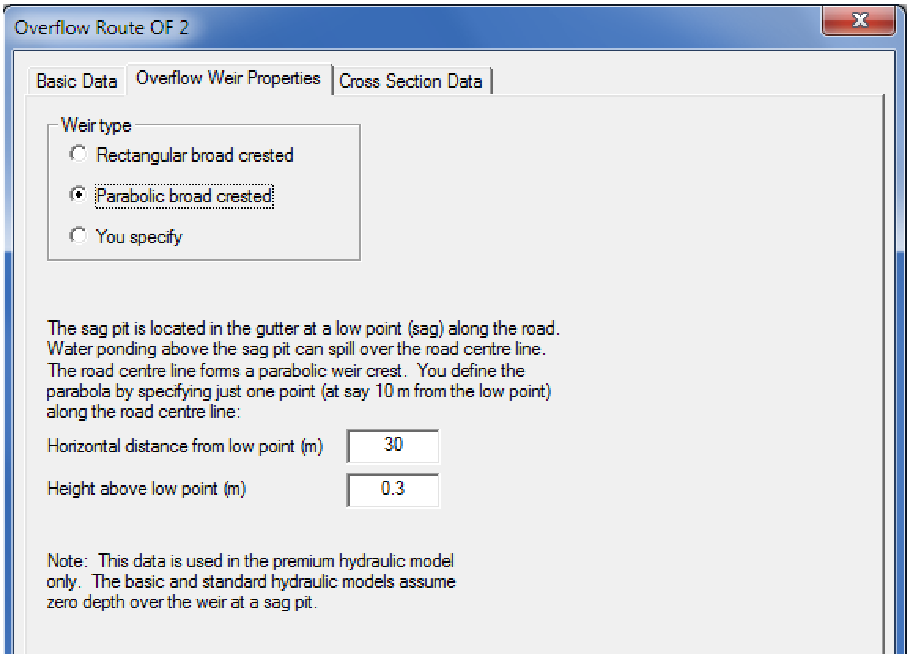


Figure 1.45 Specification of Overflow Weir for a Sag Pit

In Step (c), when a Design run is made and followed by an analysis, the results appear similar to those obtained with the ILSAX hydrology, as shown in Figure 1.43. A difference is that only peak flows are generated, rather than a full hydrograph, as shown in Figure 1.32 and Figure 1.35, so that detention storages cannot be modelled using the rational method.

Steps (d) and (e) proceed in the same manner as with the ILSAX hydrology. An Analysis run can be made to determine major storm effects, but this will not be as accurate as major system results derived using hydrographs in the ILSAX model.

The run proceeds, with *DRAINS* adding invert levels for overflow routes. The cross-sections and roughnesses specified for overflow routes are used with the lengths to performing routing calculations that will usually reduce flowrates. A more detailed modelling of sag pit storages will add to this effect. Results for the Orange examples are shown in Figure 1.46. It is possible to plot long sections for overflow routes, determining flow characteristics along these.

An animation (Figure 1.47) of the changing HGL levels in a selected part of the system can also be run from premium hydraulic model results.

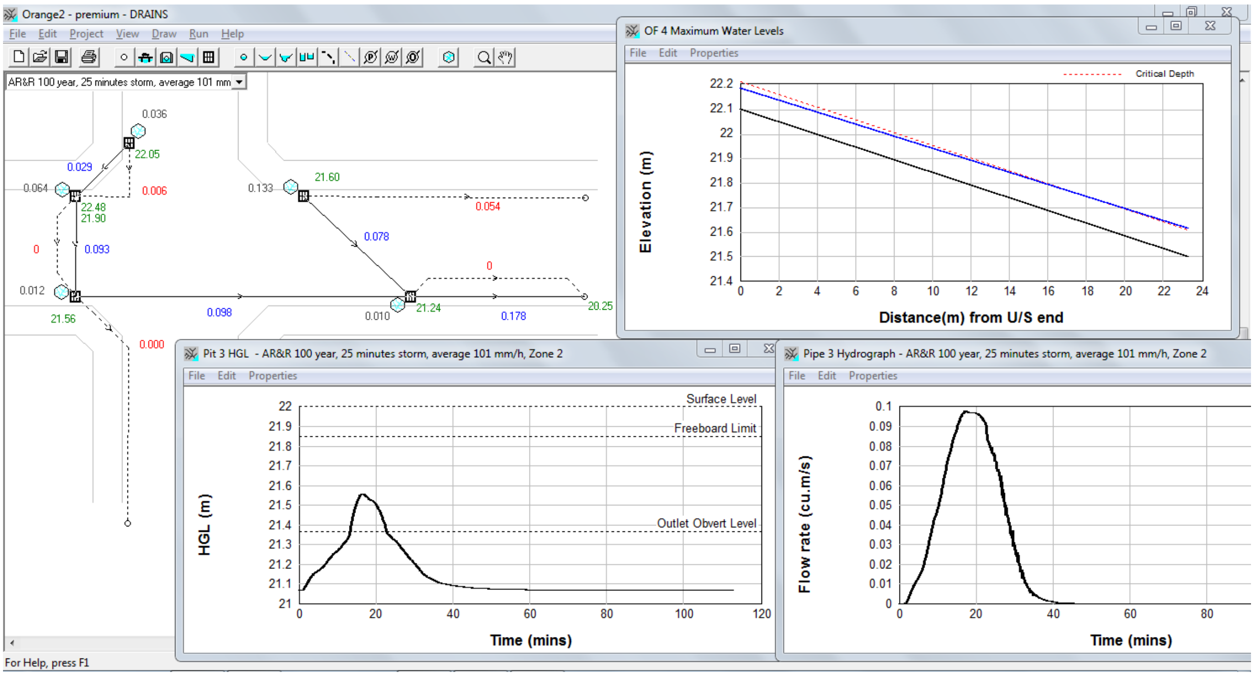


Figure 1.46 Results from Premium Hydraulic Model for a Major Storm

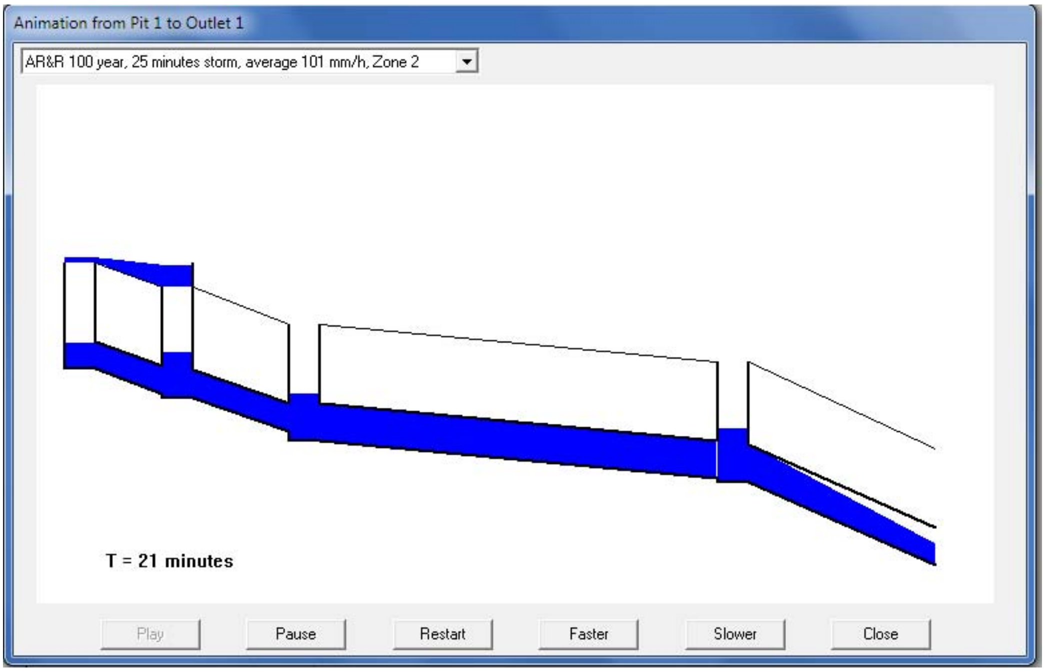


Figure 1.47 Animation of Flow Along Main Line of Orange System in a Major Storm

1.2.4 Running Storage Routing Models

Storage routing models can be implemented using many of the same features and processes used with the ILSAX and rational method programs. To illustrate this, consider the RAFTS Model shown in Figure 1.48, modelling a hypothetical creek at Shepparton, Victoria.

This rural catchment has been divided into four sub-areas, and a RAFTS model has been superimposed on this. The four sub-catchments shown by the symbol  are sites where conversions from rainfall to runoff and routing processes occur. Routing can also occur, if required, in the stream routing reaches (shown dashed).

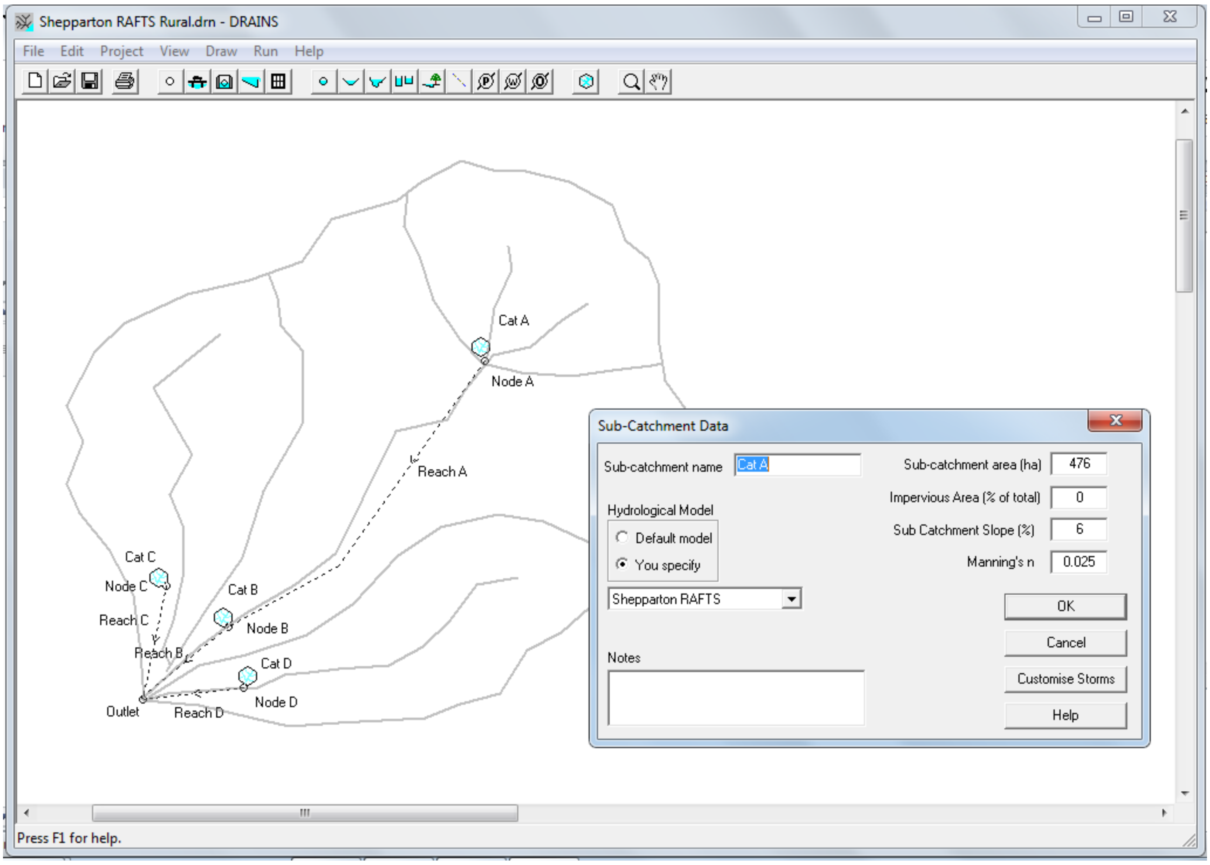


Figure 1.48 Shepparton RAFTS Model

Loss information and the routing parameter BX are entered in the hydrological model property sheet shown in Figure 1.49. Rainfall data is entered in the same way as for ILSAX models. Property sheets for a sub-catchment and a stream routing reach are shown in Figure 1.48 and Figure 1.50.

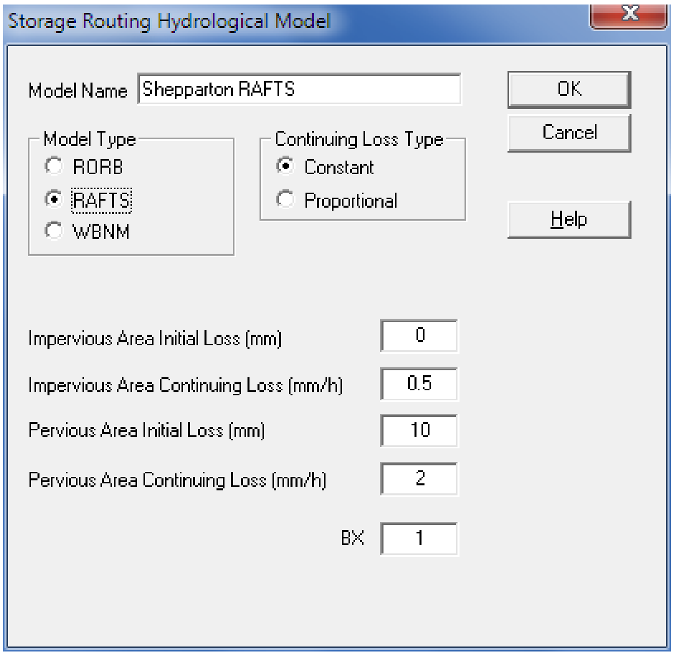


Figure 1.49 RAFTS Hydrological Model Property Sheet

The stream reach property sheet offers a choice of translation of the hydrograph (movement of flows without changing the hydrograph shape) or an approximate routing procedure based on kinematic wave hydraulic principles.

A name must be entered for nodes, but surface levels are not required, as the routing is not tied to particular elevations or datum levels. Detention basins and completely-defined open channels can be added if desired.

Results from a major storm run involving four storms of different durations are shown in Figure 1.51. The **black** numbers at the sub-catchments represent the routed sub-catchment flows, while the pairs of **red** numbers represent the peak flowrates at the top and bottom ends of a reach. Hydrographs can be examined easily and data can be transferred to a spreadsheet.

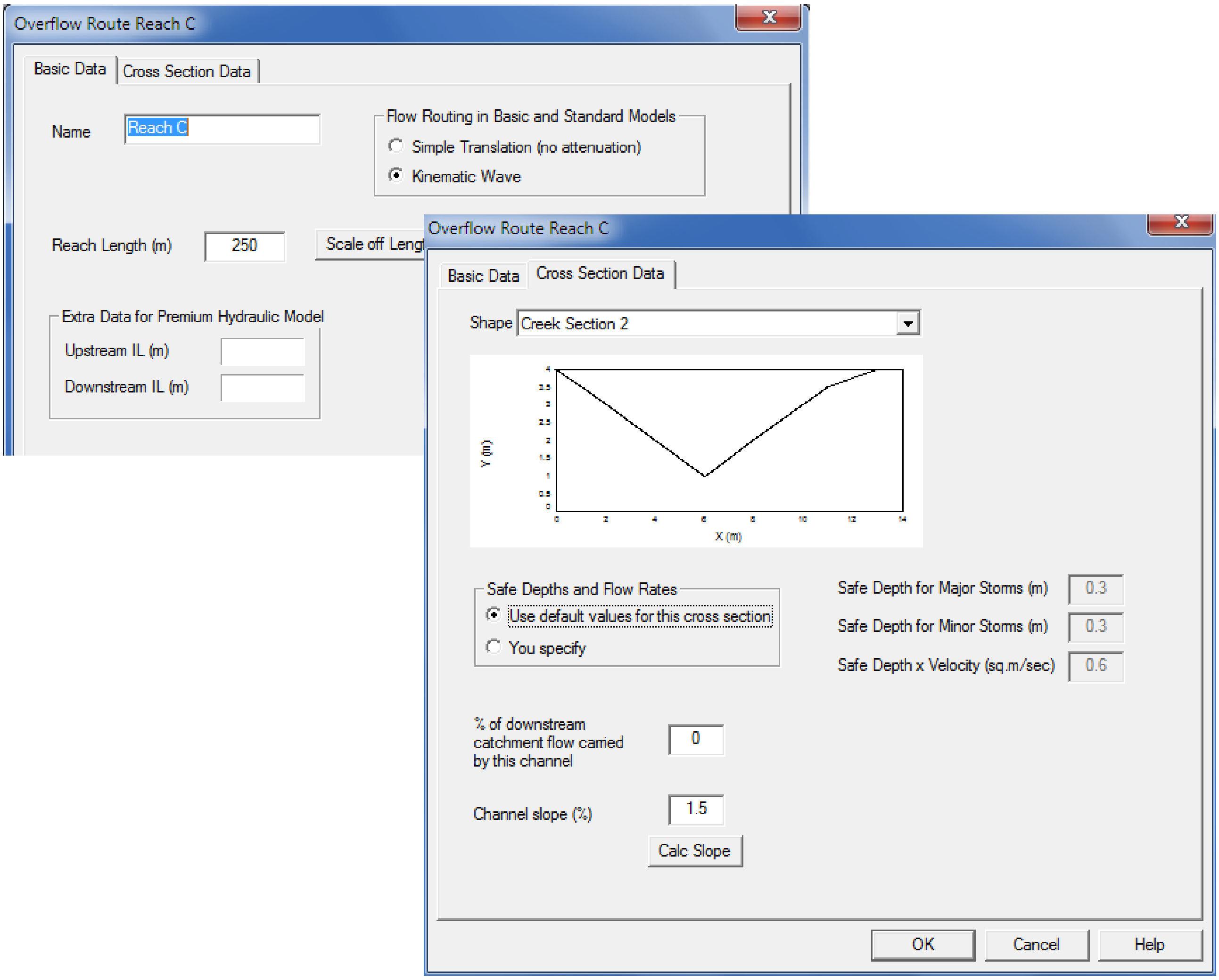


Figure 1.50 RAFTS Stream Routing Reach Property Sheet

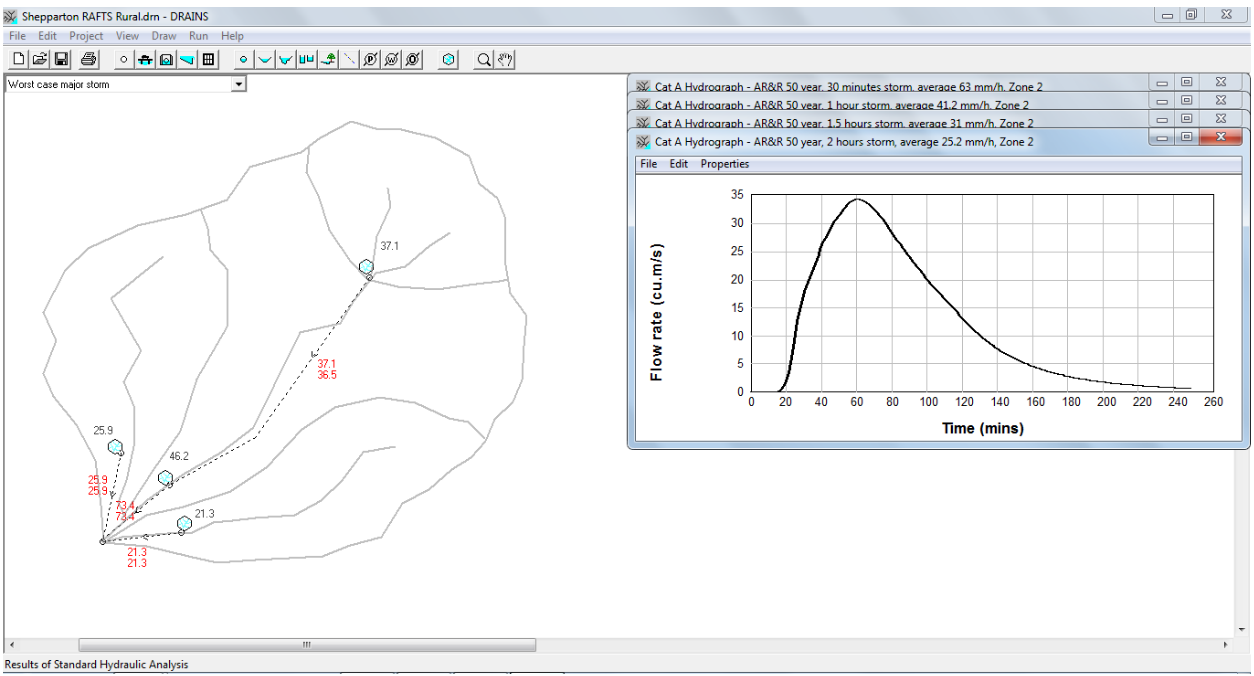


Figure 1.51 Results of Storage Routing Run

2. MENUS, TOOLS AND DATA BASES

2.1 Introduction

This chapter presents the options and tools that are used to create and tailor *DRAINS* models. Drainage systems can be created with the tools on the Toolbar, or can be partially imported using menu options. With optional modules covering rational method, storage routing, GIS transfers, GIS transfers, and premium hydraulic modelling, there are different forms of some menus and property sheets to those described here.

These facilities are explained in the following sections together with the data bases that store information on hydrological models, rainfall patterns and components such as pits. The exposition is detailed and systematic, and is likely to be boring unless you check through each item using the *DRAINS* demonstration examples, or if you have a hardware lock to run the program fully, the example file **`Toowoomba Estate. Drn`**, shown in Figure 2.1.

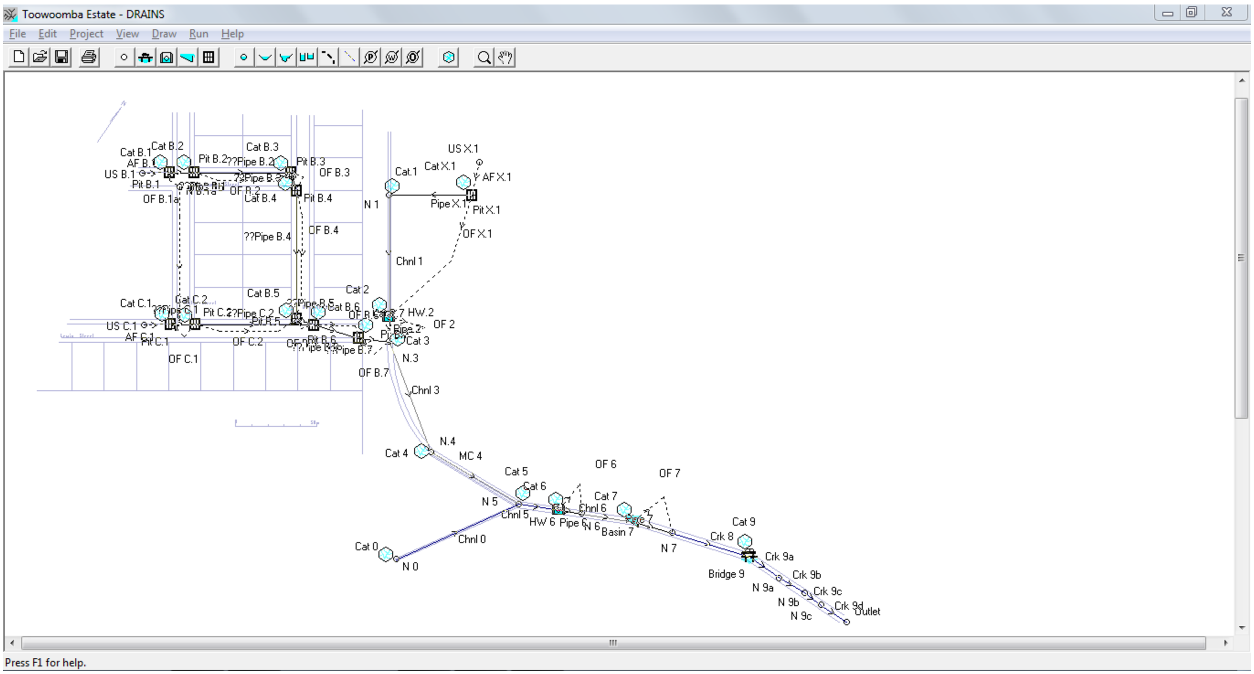


Figure 2.1 Hypothetical Toowoomba Example

2.2 Menus

2.2.1 The Menu Bar

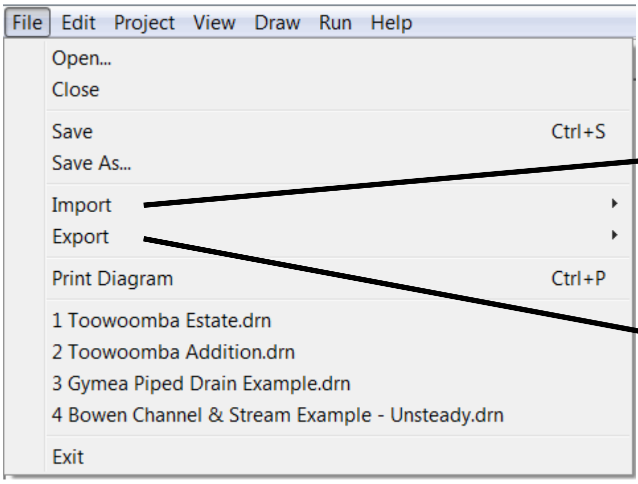
DRAINS employs seven drop-down menus opened from the items in the menu bar:

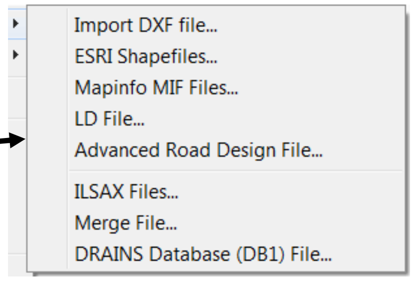
File Edit Project View Draw Run Help

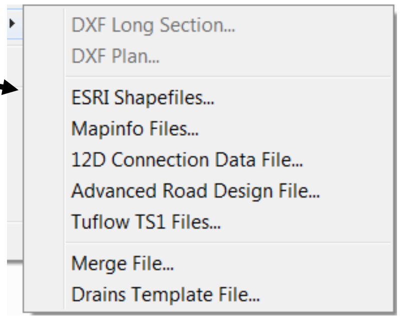
The broad functions of each menu are described below. You will find material on individual functions in other parts of this manual. Refer to the index for the locations of these.

2.2.2 The File Menu

This menu controls most ways of inputting and outputting data. The functions of creating new files, opening and closing stored files, saving and 'saving as' files, and exiting are carried out using standard Windows procedures. Through the additional menus shown below, called through the **Import** ► and **Export** ► options in the **File** menu, information can be taken in and out of *DRAINS* in various file formats, which are covered in detail in Chapters 3 and 5.

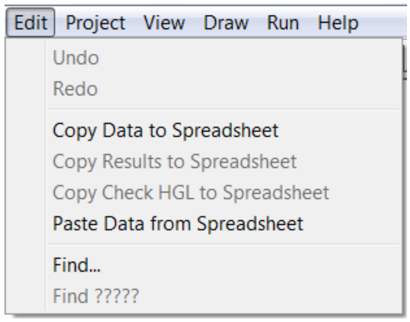






If a *DRAINS* model already has a background, the first option in the **File** → **Import** ► option will be **Import DXF background…** instead of **Import DXF file...** in a new model. This enables the background to be changed or updated.

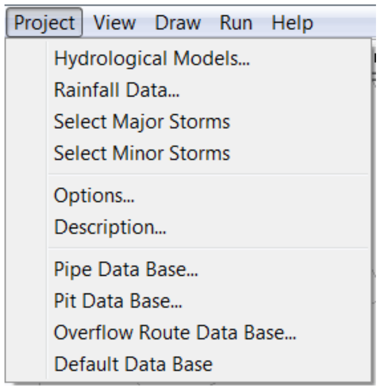
2.2.3 The Edit Menu



This contains functions like Undo and Redo, and Find facilities for locating components in large drainage networks.

The commands for transferring data and results to and from spreadsheets are also included here.

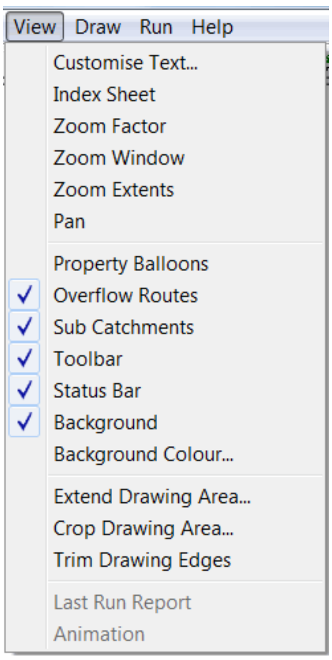
2.2.4 The Project Menu



This menu accesses information for the particular drainage system being analysed by *DRAINS*, as well as the pipe, pit and overflow route data bases.

It also allows a new data base to be loaded as the standard data base.

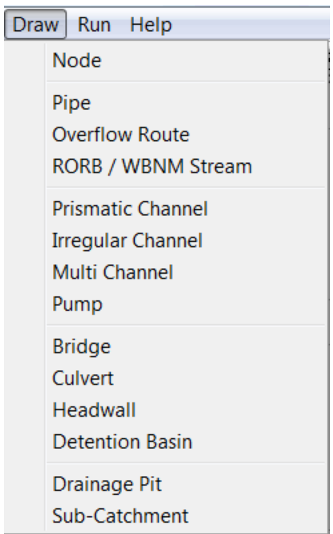
2.2.5 The View Menu



This menu provides options for viewing data and results in different ways.

It controls what is shown in the Main Window. See Section 3.3 for a description of the options.

2.2.6 The Draw Menu



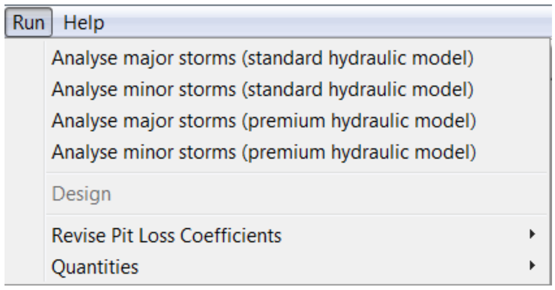
This duplicates the Toolbar choices. Selecting an option has the same effect as clicking on a button in the toolbar.

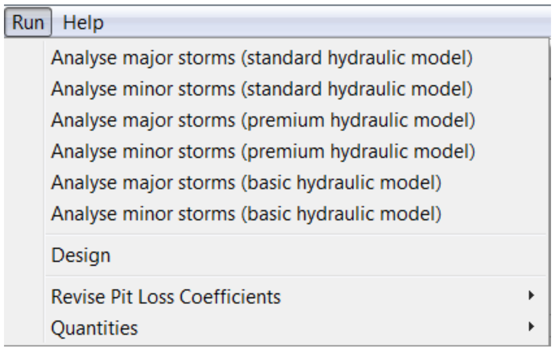
2.2.7 The Run Menu

This includes various options for making runs, and for varying these. Depending on circumstances, this menu can take different forms, the first, shown to the right, being for new models.

For models created prior to December 2010, it is also possible to run with the obsolete basic hydraulic model, which has been replaced by the standard model.

The run menus for rational method models and for storage routing models will be less complicated than those shown.

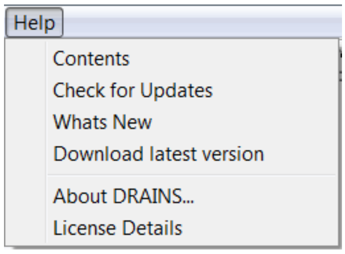




2.2.8 The Help Menu

This contains an access point to the Help system through the **Contents** option, and also identifies the version of *DRAINS* and allows the capabilities set by the hardware lock to be upgraded using passwords.

Where an item in a menu list is followed by '…' or ' ►' it opens another menu, a dialog box or property sheet.



2.3 Tools and Associated Components

2.3.1 General

DRAINS provides 21 buttons in the Toolbar:

The first four buttons are for creating a new file, opening an existing file, saving a file and printing the Main Window, duplicating functions in the **File** menu. The last two buttons are the Zoom Factor function that is also available in the **View** window, and the Pan function.

The remaining fifteen buttons can be used to draw components in drainage systems in the Main Window. The first group of five are all nodes or junctions; the next group of nine are links, and the remaining sub-catchment button provides a source of water as runoff derived from rainfalls. If you hold your mouse arrow over each button, a ScreenTip will appear to indicate its function.

Clicking on these buttons changes the cursor from an arrow to a pencil, which is used to place components in the Main Window. Holding down the **Shift** key while entering a component retains the pencil cursor after you have entered a component, allowing you to add another component of the same type. If you become 'stuck', with the cursor still in pencil form when you no longer want to enter a component, simply enter the component and then delete it.

Components should connect properly. The ends of links should be placed near the centre of nodes, and sub-catchments should clearly connect to pits and nodes. Sub-catchments must not be placed over pits, or overflow routes over pipes, as it will be difficult to select particular components later. The layout should be tidy, to enable components to be viewed and accessed easily. Names and positions of components can be shifted to clarify the layout.

A background layer imported as a DXF file from a CAD program, as described in Section 3.2.2, or as part of the importation of GIS files (Section 3.2.4), provides a guide for locating pits and other components.

Behind each of the components provided in *DRAINS* is a computer algorithm (logic + equations + data) that is employed within calculation frameworks. There are often alternative ways to describe the operations of components such as pits or detention basins. When performing analysis work with *DRAINS*, you should assess the methods and equations used in the program (detailed in Chapter 6) and examine results, to confirm that the program operates as you expect.

You may encounter situations that are not fully described by the standard components, such as a complex system of detention basins. It will then be up to your judgement and modelling skills to use the available tools to describe the situation. This may involve 'tweaking' of the model. An example of this type of manipulation is the use of detention basins to simulate stormwater infiltration systems or pumps, as noted in Section 2.3.7.

The following sections describe the features of each component, starting with those that you are likely to use most frequently.

2.3.2 Pits

(a) General

Pits, like other forms of node, act as entry points for water into the pipe system. They can represent a street gully pit, a manhole, a junction, a flow diversion or other components.

On-grade pits are located on slopes, while sag pits are in hollows or depressions, as shown in Figure 2.2. When stormwater runoff reaches an on-grade pit, at smaller flowrates all flows are collected. As approach flowrates increase, a point is reached where some bypass flow occurs. This will flow away from the pit, perhaps to another pit downstream, with additional flows joining it along the way. To model on-grade pits, a relationship between the approach flow and the flow captured by the pit must be specified. These cannot be established by theory and are usually determined from modelling studies or tests on installed pits, as is discussed further in Section 5.5.

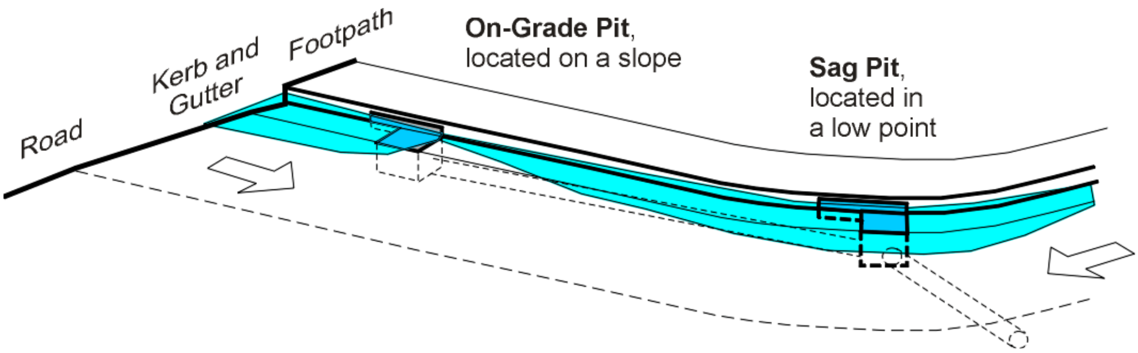


Figure 2.2 On-Grade and Sag Pits

(b) On-Grade Pits

The Drainage Pit property sheet can take two forms, depending on the type of pit selected.

The on-grade pit property sheet, shown in Figure 2.3, requires the following inputs:

- a pit name of up to 10 characters (including blanks);
- a surface elevation (m) (This can be arbitrary, but it is recommended that you work with a standard datum such as Australian Height Datum (AHD).);
- a pit family and size, defined using drop-down lists linked to inlet capacity information set up in the Pit Data Base, as described in Section 2.4.6. (A pit type must be established in the Pit Data Base for all the pit families used.);
- a dimensionless pit pressure change coefficient for full pipe flow, which defines the change in the hydraulic grade line (HGL) at a pit, due to turbulence and other effects. (Pit pressure changes are explained in Section 0 and *DRAINS* offers methods for automatically calculating these. Some typical values are presented in Table 2.1.)

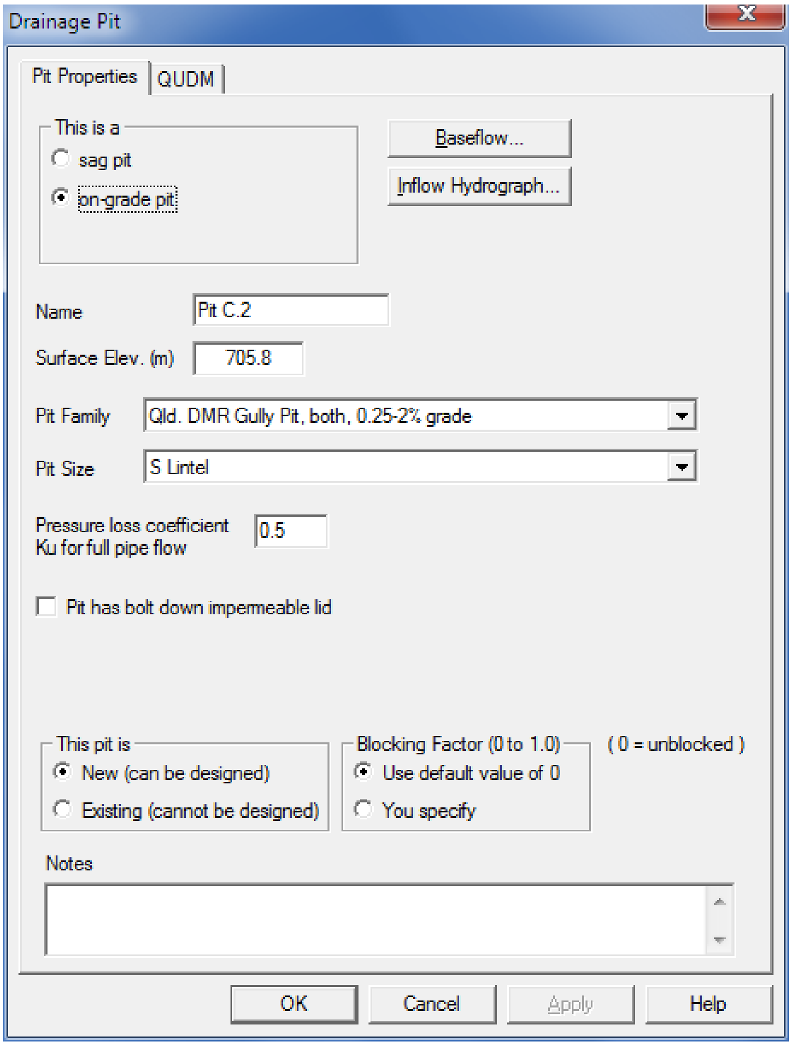


Figure 2.3 Drainage Pit Property Sheet for an On-Grade Pit - First Page

Table 2.1 Approximate Pit Pressure Change Coefficients, k_u

Type of Pit	**k_u**
Pit at the top of a line	5.0
Pit with a straight through flow, no sidelines, no grate inflow	0.1
Pit with a straight through flow, no sidelines, 50% grate inflow	1.4
Pit with a right angle direction change, no sidelines	1.7
Pit with a straight through flow, one or more sidelines	2.2
Pit with a right angle direction change from two opposed inflow pipes	2.0

On this property sheet there is also a check box with the label 'Pit has bolt-down impermeable lid' that allows pits to be sealed, and the HGL may rise above the surface. A sealed pit cannot accept flows at the surface, and cannot overflow.

In the sheet there is also provision for specifying blocking factors, default values of which can be set in the **Options** property sheet opened from the **Project** menu as shown in Figure 1.12. The inlet capacity calculated from the relationship obtained from the Pit Data Base is multiplied by 1 minus the blocking factor. Thus a factor of 0.2 will reduce the inlet capacity or capture rate by 20%. More restrictive blocking factors are usually applied for sag pits than for on-grade pits. Values of 0.5 for sag pits and 0.2 for on-grade pits are typically used, though the latter in particular is questionable.

On the second page with the tag 'QUDM' shown in Figure 2.4, you can nominate whether the pit is aligned or misaligned and to provide the pit wall width (in mm) at the location of the outlet pipe. (This is only required if you wish to apply the QUDM Chart procedure to define pit pressure change coefficients.

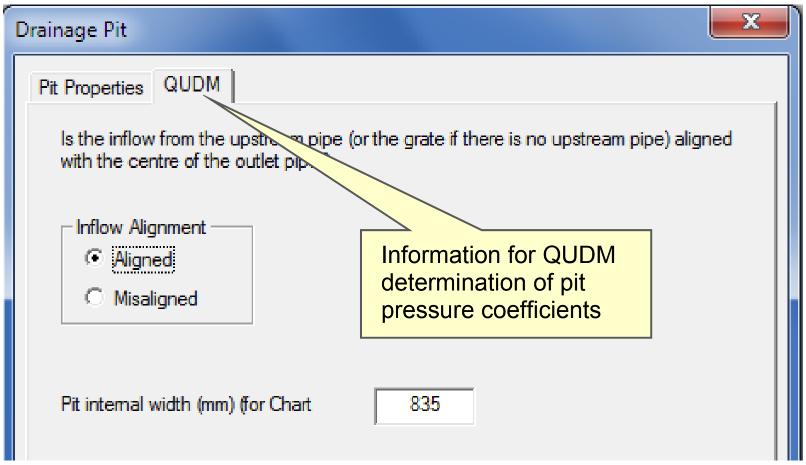


Figure 2.4 Drainage Pit Property Sheet for an On-Grade Pit - Second Page

The original blockage calculation process in *DRAINS* simply multiplied the inflow capacities for an on-grade pit by a constant blockage factor. The same percentage reduction applied for low and high approach flows. The blocking theory that is now applied results in a lower reduction at low approach flows and an increasing blockage effect with increasing flowrates, up to the specified factor. An further explanation is shown in Figure 2.5.

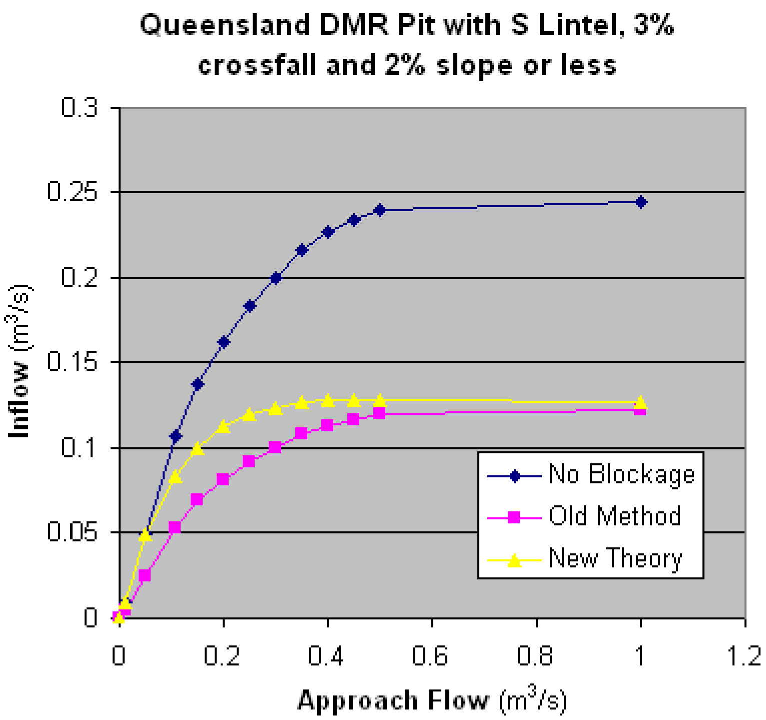


Figure 2.5 Inlet Capacity Relationships allowing for 0.5 (50%) Blocking Factor

In older *DRAINS* models the method to be applied could be set in the Options property sheet (
Figure 1.12

A pit can be excluded from the design process using the **This pit is** buttons at the bottom left of the property sheet.

(c) Sag Pits

For sag pits, the Drainage Pit property sheet appears as shown in Figure 2.6. It is necessary to enter the same information as for an on-grade pit, with additional data required for water that might form a pool over the pit. It is necessary to specify the maximum ponded depth and the corresponding volume of ponded water over the pit.

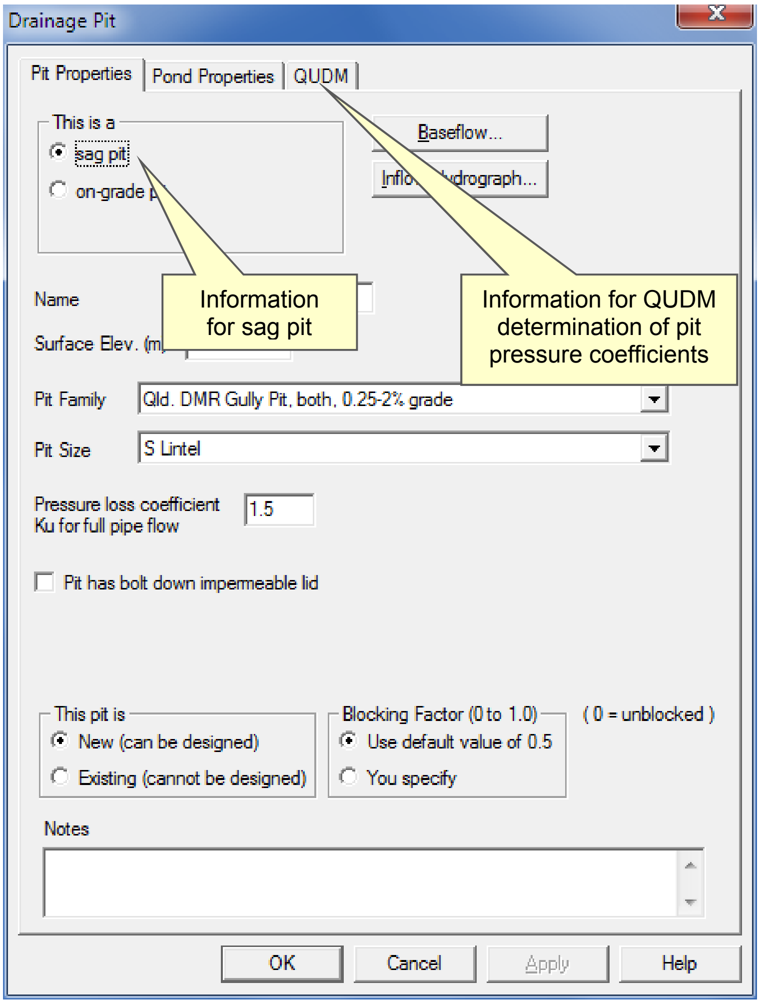


Figure 2.6 Drainage Pit Property Sheet for a Sag Pit (Upper Part)

DRAINS will make the ponding area overflow if the water depth exceeds the maximum ponded depth specified in the pit property sheet. Where two sag pits are connected by an overflow route, the overflow level of the upper one (its surface level + ponding depth) should be higher than the overflow level of the lower pit, as shown in Figure 2.7. Otherwise, in basic and standard hydraulic model calculations, *DRAINS* will have overflows going 'uphill' and will display a warning message, either prior to running a model, or in the report at the end of a run.

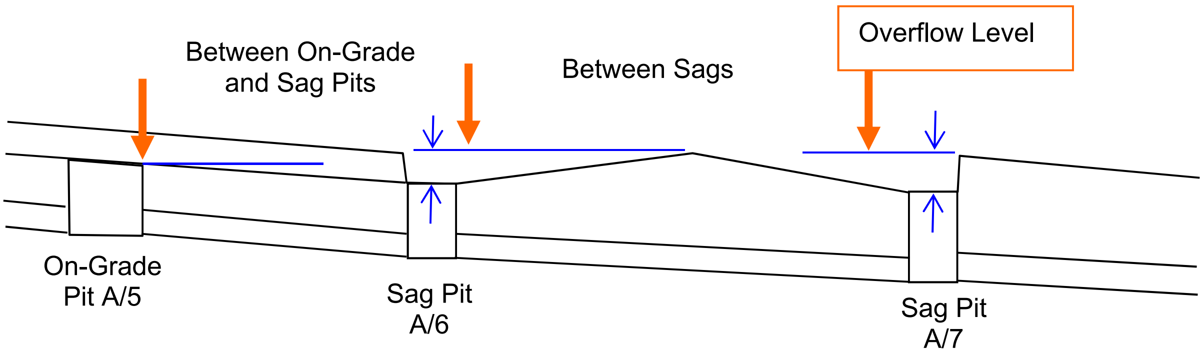


Figure 2.7 Relative Overflow Levels

The overflow level of a sag pit is below the surface level of an on-grade pit that overflows to the sag pit, otherwise messages regarding uphill overflows will appear. In reality, on-grade pits may be submerged by ponding over a nearby sag pit, as is the case in Figure 2.7.

(d) Baseflows and Direct Hydrographs

As well as receiving surface flows, a pit can receive a constant baseflow or a user-provided inflow hydrograph, specified using the buttons at the top of the Drainage Pit property sheet. These can be introduced at the surface or inside the pit. Flows introduced inside the pit are not subject to the pit inlet capacity relationship.

When the **Baseflow…** button is clicked, the property sheet shown in Figure 2.8 appears. Only a single flowrate is entered.

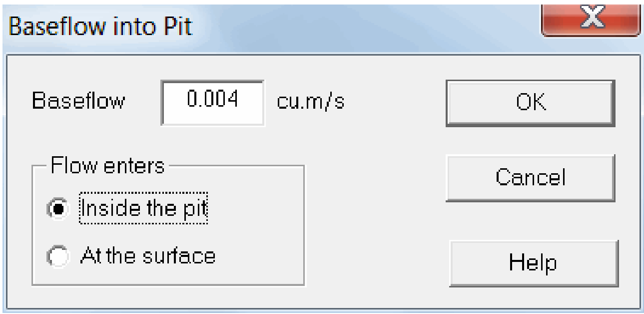


Figure 2.8 Baseflow Property Sheet

When the **Inflow Hydrograph…** button is clicked, the window shown in Figure 2.9 is opened.
To specify a hydrograph a set of hydrograph ordinates, or flowrates at particular times, must be entered in the text boxes labelled 'Time (mins)' and 'Flow (cu.m/s)'. The graph assists the entry of data by providing a visual guide. Specific ordinates can be located and altered using the arrows in the spin box associated with the times.

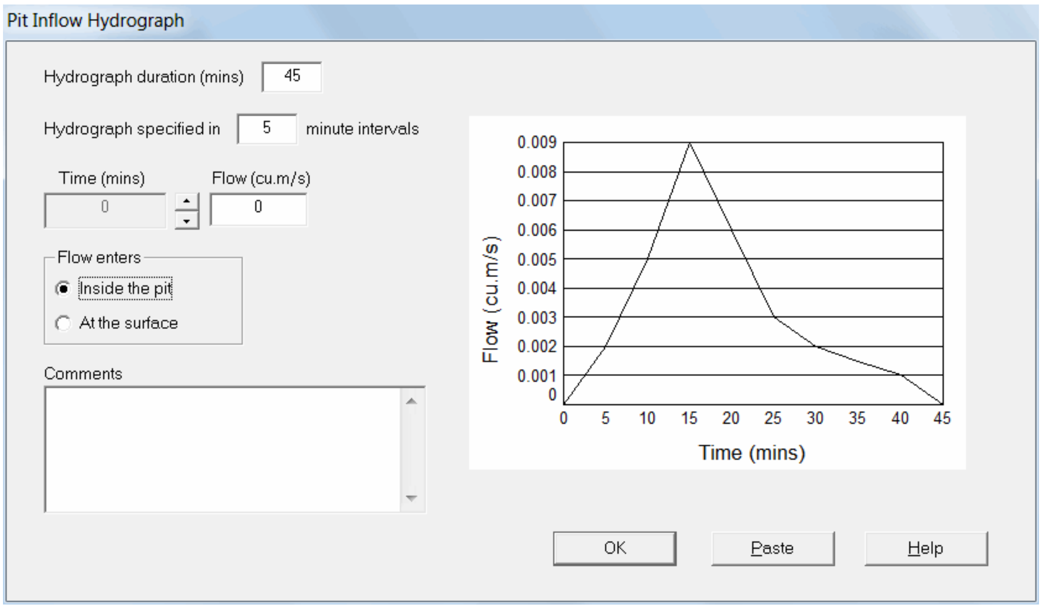


Figure 2.9 User-Provided Inflow Hydrograph for Pits

Hydrographs can also be entered from a spreadsheet. You must prepare two columns in a spreadsheet program such as Excel, one containing times at fixed intervals in minutes, starting at zero, and the other containing the values of flowrates in m^3/s. You then select these columns and copy them to the Clipboard. Switching from the spreadsheet program to *DRAINS*, you can then open the Pit Inflow Hydrograph property sheet and import the data by clicking the **Paste** button.

The presence of baseflows or input hydrographs is not obvious when models are inspected. They can be located by exporting the data to a spreadsheet, as shown in Section 3.5.4, and inspecting the pit and node data. Columns I and P of the spreadsheet output (**Figure 1.33**) show the values of baseflows and the presence of direct hydrographs.

2.3.3 Simple Nodes

The most basic type of node, called a simple node, can be used for several purposes:

- to represent an outlet,
- to act as a junction linking reaches in an open channel drainage system,
- to provide a junction for stream reaches in a storage routing model,
- to act as a closed, no-loss junction in a pipe system, and

- to provide a joining point for sections of overflow routes.

DRAINS detects whether a node is at an outlet to a system, and if so, it presents the property sheet shown in Figure 2.10. As explained in Chapter 5, for part-full pipe flows *DRAINS* projects hydraulic grade lines upstream through a drainage system. If a free outfall is specified, the starting point for this upwards projection at each time step is the higher of the pipe's normal and critical depths for the current flowrate. If a tailwater level higher than these depths is specified in the Outlet Node property sheet, this becomes the starting level.

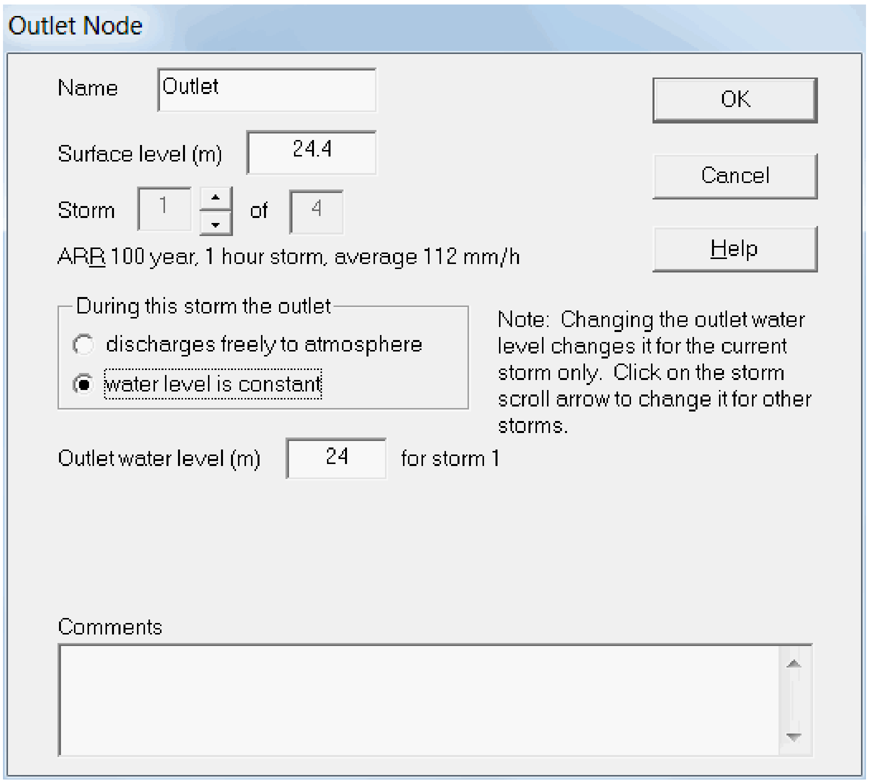


Figure 2.10 Outlet Node Property Sheet

Intermediate nodes connecting pipes, open channel systems and overflow routes appear as shown in Figure 2.11, with a surface level required. Nodes that link stream routing reaches in a storage routing model have the same property sheet, but no surface level is required, only the node name.

A baseflow or user-provided inflow hydrograph can be entered at each node, by clicking on the corresponding buttons in the node property sheet. This will open property sheets similar to those in Figure 2.8 and Figure 2.9.

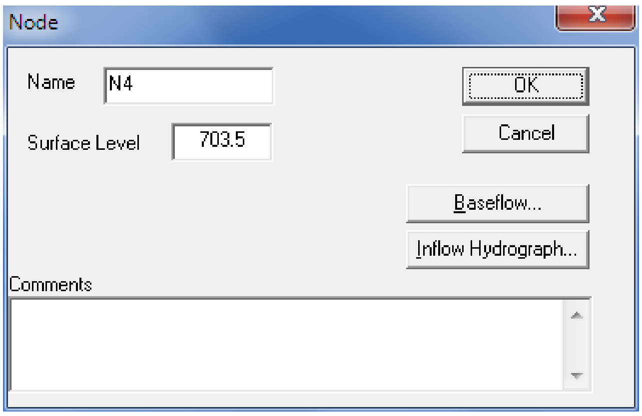


Figure 2.11 Property Sheet for an Intermediate Node

2.3.4 Pipes

The Pipe property sheet shown in Figure 2.12 requires, as a minimum, that you enter a name, length and number of parallel pipes (default value 1), and specify a pipe type from the drop-down list box.

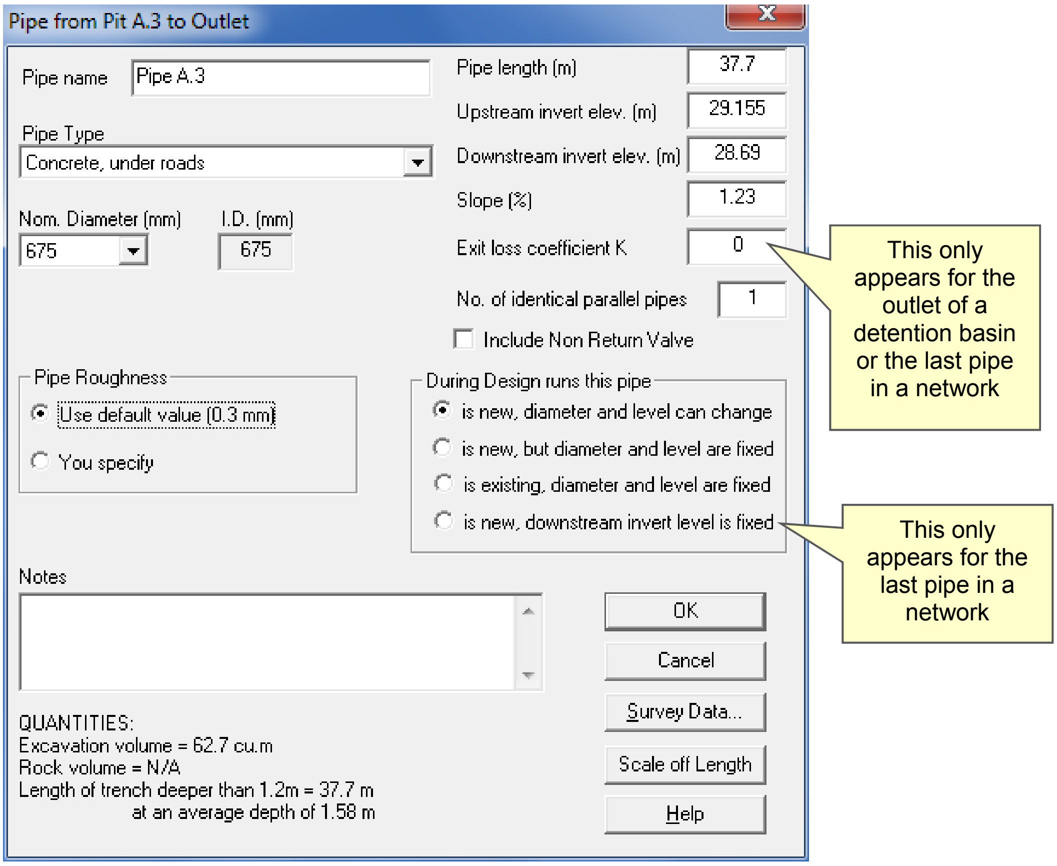


Figure 2.12 Pipe Property Sheet

This information is sufficient for a Design run, in which *DRAINS* will specify the pipe diameter and invert levels. The pipe type chosen must be defined beforehand in the Pipe Data Base located under the **Project** menu options. Pipe lengths can be scaled from coordinates if the system is drawn to scale. Rectangular pipes can be used, though not for design, and minimum pipe diameters can be set for design in the manner described in Section 2.4.5.

If the pipe's characteristics are already known, its diameter and invert levels can be specified. If it is not to intended to change these in a Design run, the second or third choices in the 'During Design runs' box should be selected. The fourth choice only applies to the last pipe in a network. It allows the system to be designed to match a specified pipe invert level at the outlet, even if this violates constraints on the minimum allowable pipe cover and minimum slope.

The **Survey Data…** button at the bottom of the sheet opens the property sheet shown in Figure 2.13.

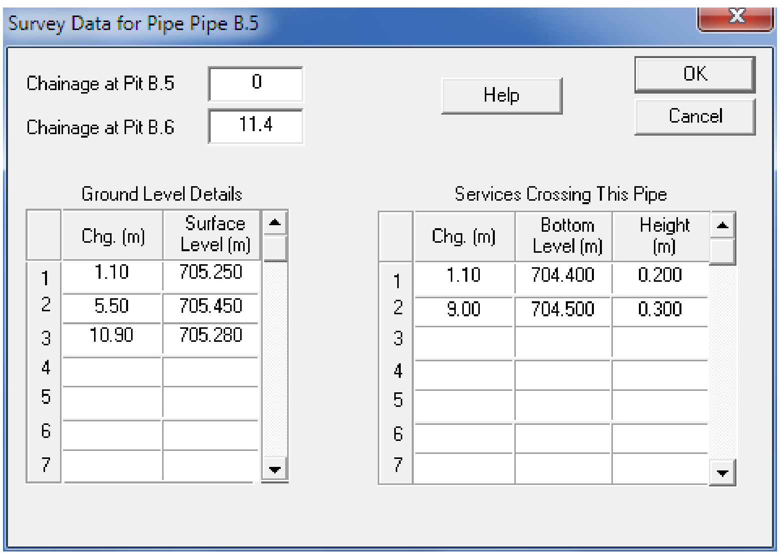
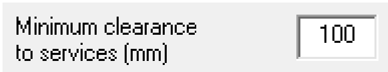


Figure 2.13 Survey Data Property Sheet for Defining Intermediate Levels along a Pipe Line and Positions of Services

Surface levels can be entered at given chainages along the line of the pipe, so that the design procedure can allow for minimum cover all along the pipe. Intermediate points can be plotted in a long-section drawing, as shown in Figure 2.14. This property sheet also allows the positions of other services to be defined so that *DRAINS* can avoid these (allowing for a vertical clearance defined in the **Options**… property sheet in the **Project** menu, as shown below.



In Design runs, *DRAINS* tries to locate pipes between services, going under them if no other route is possible. If this is unacceptable, the designer can selectively remove services, or make manual adjustments to the pipe cross-section and/or alignment.

The long section display in Figure 2.14 shows how the ground levels and service positions appear after a Design run is carried out, using the **Long Section** option in the pop-up menu for the pipe. The position of the pipe is defined by the intermediate low point in the surface. The pipe fits comfortably under the services, shown in red, and the required clearance, shown in yellow.

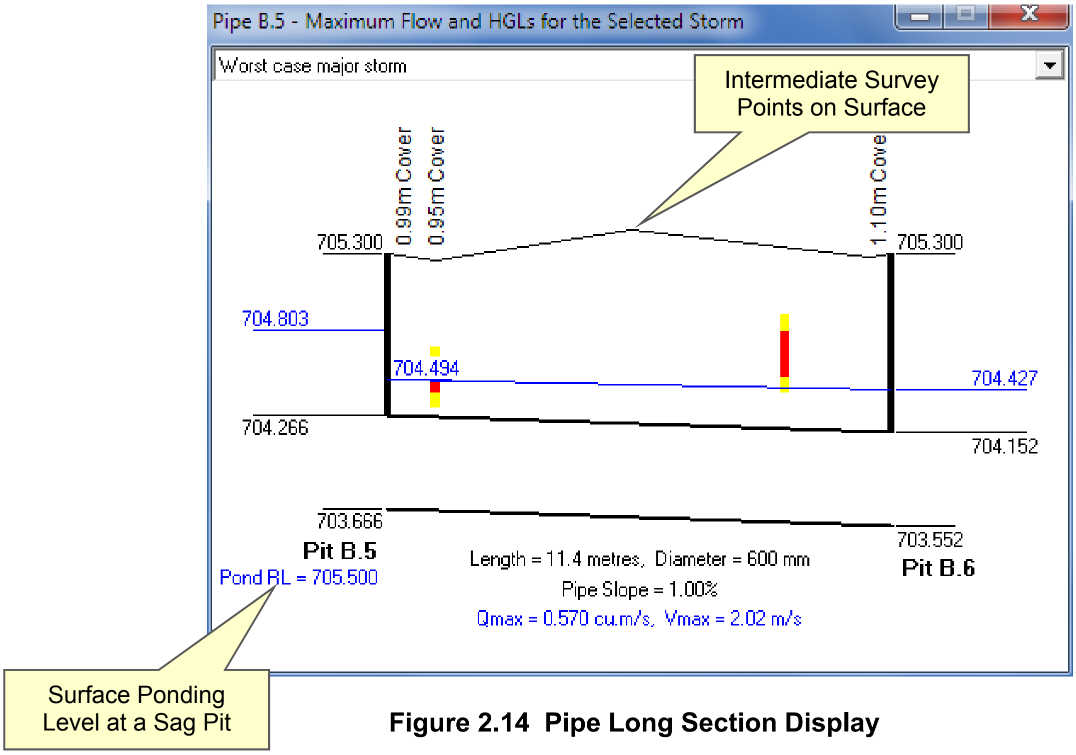


Figure 2.14 Pipe Long Section Display

In some cases, a non-return device such as a flap gate may be installed in a pipe, preventing flows from moving upstream. This can be modelled by ticking the **Include Non Return Valve** box in the Pipe property sheet.

2.3.5 Sub-Catchments

(a) ILSAX Model Sub-Catchments

The form of the property sheet for a sub-catchment depends on the hydrological model defined in the **Hydrological Models…** option in the **Project** menu, as shown in Figure 1.4 and Figure 1.5. If an ILSAX type model is chosen, the sub-catchment can be divided into the paved, grassed and supplementary land-surface types illustrated in Figure 2.15:

- paved area (impervious areas directly connected to the drainage system),
- supplementary areas (impervious areas not directly connected to the drainage system), and
- grassed areas (pervious areas, which can be lawn, bare earth, landscaped areas, bushland, porous pavement or any other pervious surface).

The supplementary area models any impervious surfaces that drain onto pervious or grassed areas, where the runoff might be absorbed into the soil. These could be sheds, swimming pools, parking lots

and other impervious areas that do not drain through pipes or over impervious surfaces to the sub-catchment outlet.

In the original specification of these land-uses in the ILLUDAS Model, Terstriep and Stall (1974) defined them using the diagrams in Figure 2.16. These indicate that the supplementary area was used to model systems where downpipes discharged directly onto grassed areas. Thus, this feature can be used to model certain water sensitive urban design (WSUD) options.

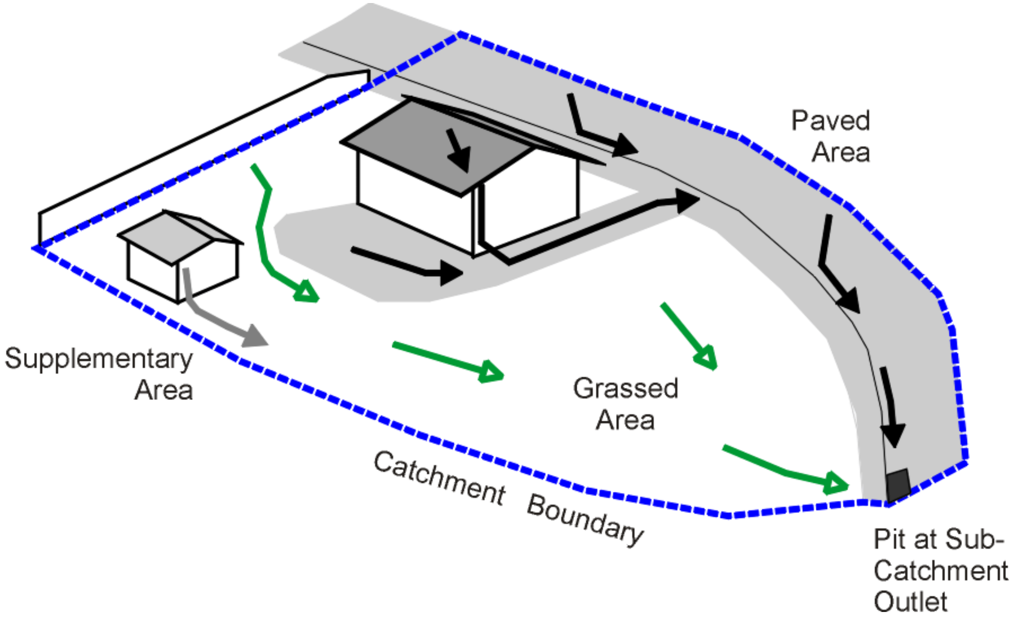


Figure 2.15 ILSAX Catchment Model Land-Use Types

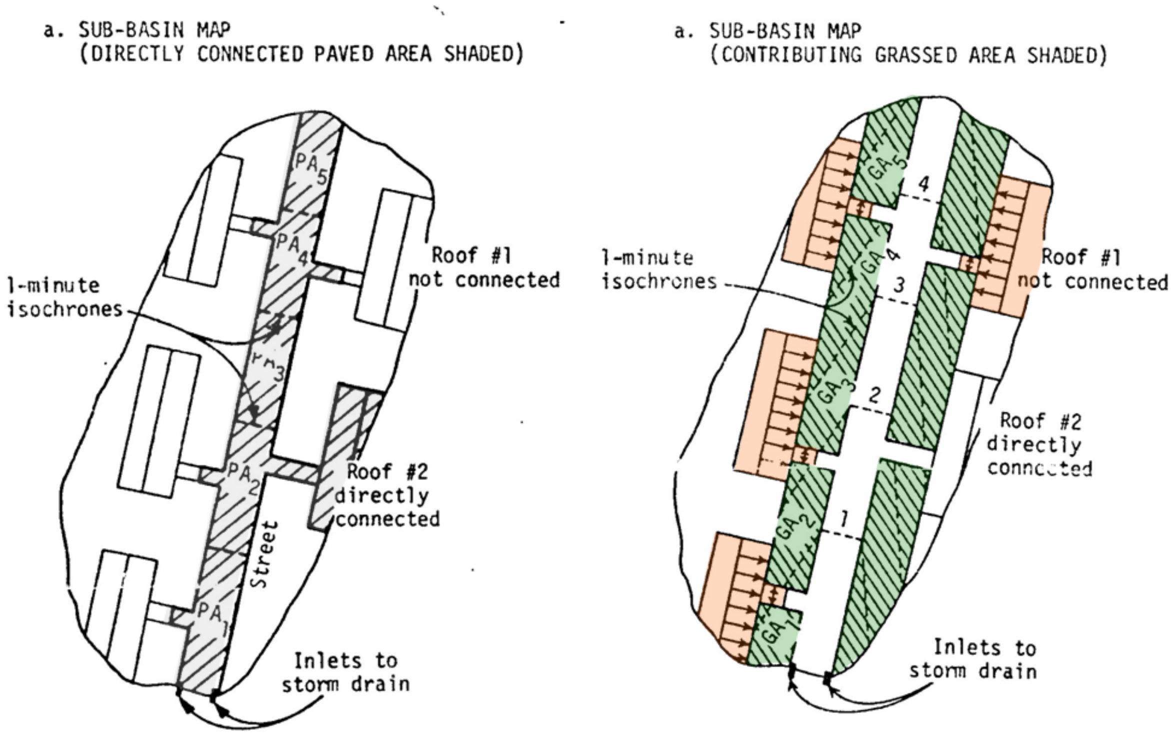


Figure 2.16 Original Definition of Land Use Areas for ILLUDAS Model

The full form of the Sub-Catchment property sheet for the ILSAX Model is shown in Figure 2.17, with the **more detailed data** option chosen in the check boxes labelled **Use**.

Figure 1.23 in the previous chapter displayed the **abbreviated data** option. In both this and the more detailed data option, you must enter the total area in hectares, and the percentages of the three land-use categories that make up the total area. The detailed option in Figure 2.17 requires additional information to establish times of entry using different flow-path components, applying the kinematic wave equation described in Section 5.3.2(d).

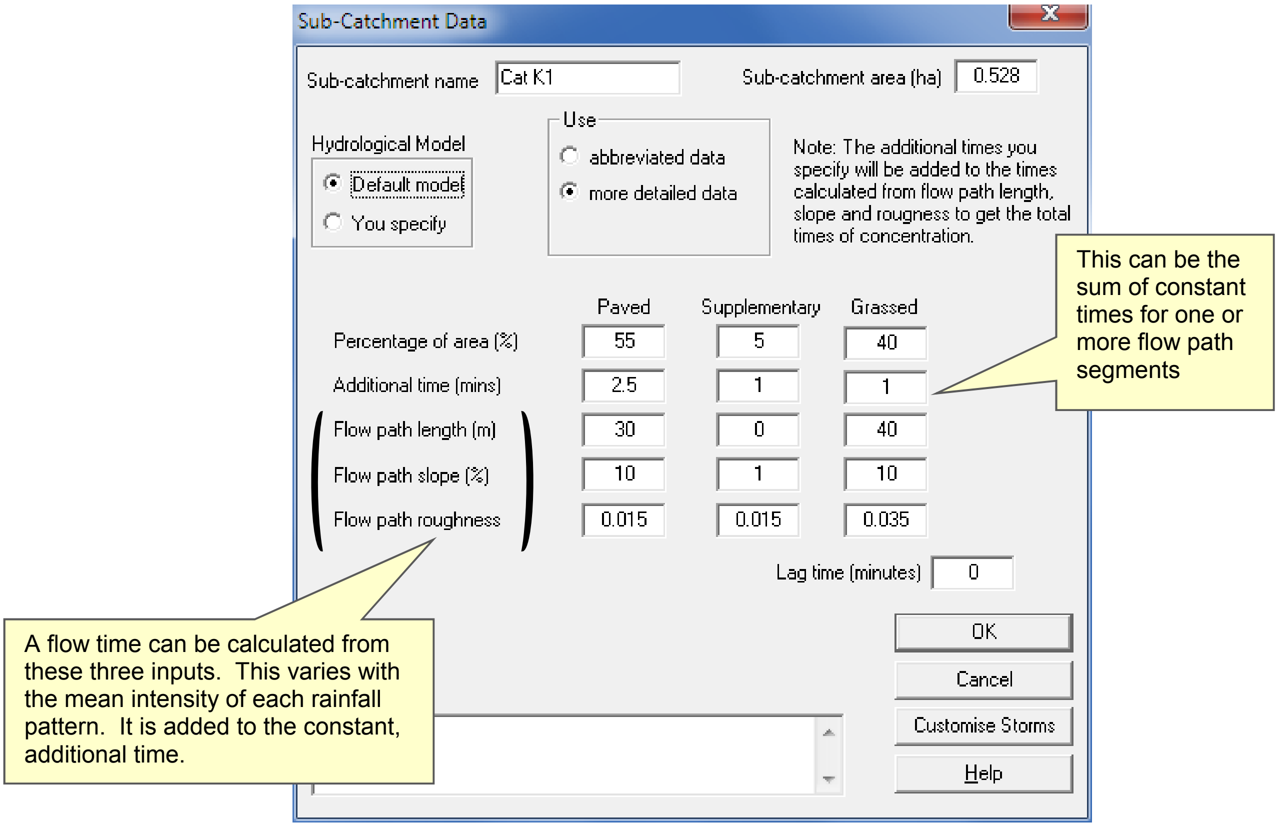


Figure 2.17 Sub-Catchment Data Property Sheet

For each of the three land-uses, there are two flow components – a constant component and a kinematic wave calculation component. A typical flow path is shown in Figure 2.18, consisting of:

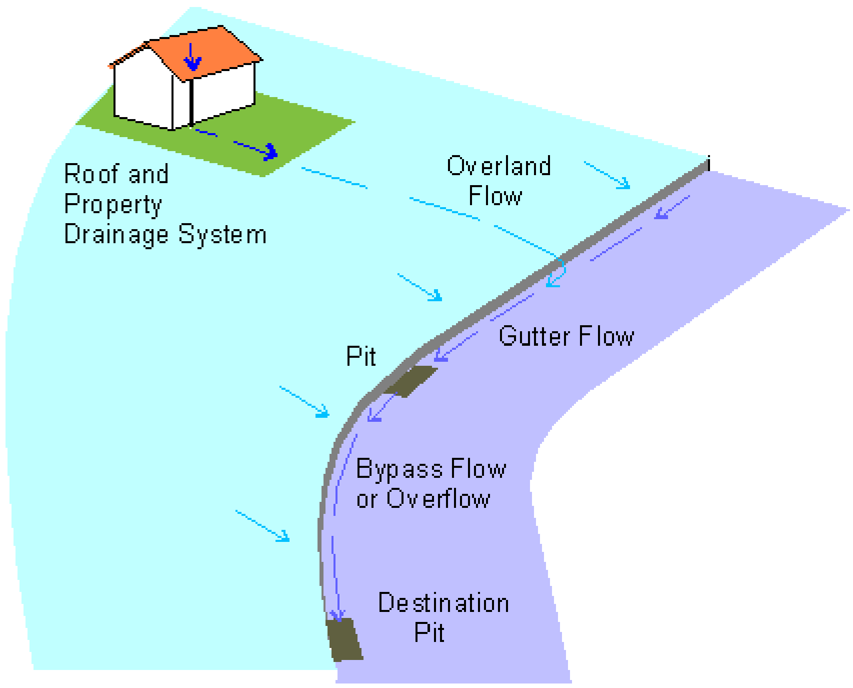


Figure 2.18 Flow Paths to a Pit

(a) a constant time for the segment from the roof of the furthest building in the sub-catchment to its property boundary (usually 1 minute for a new property drainage system or 2 minutes for an older one with possible blockages),

(b) a time to be calculated by the kinematic wave equation for the overland flow segment, using the specified length, slope and surface roughness n*, and

(c) a street gutter or channel segment (where a flow time can be calculated from an estimated velocity along the gutter).

Times (a) and (c) can be added to form the constant time in the property sheet.

A lag time can be used to delay the grassed are area runoff hydrograph by a time representing the travel time of runoff over an area of impervious surface between the lowest point on the grassed surface and the pit or node at the catchment outlet. This is illustrated in Figure 2.19. It might be used to model a constant flow time along a street gutter or channel.

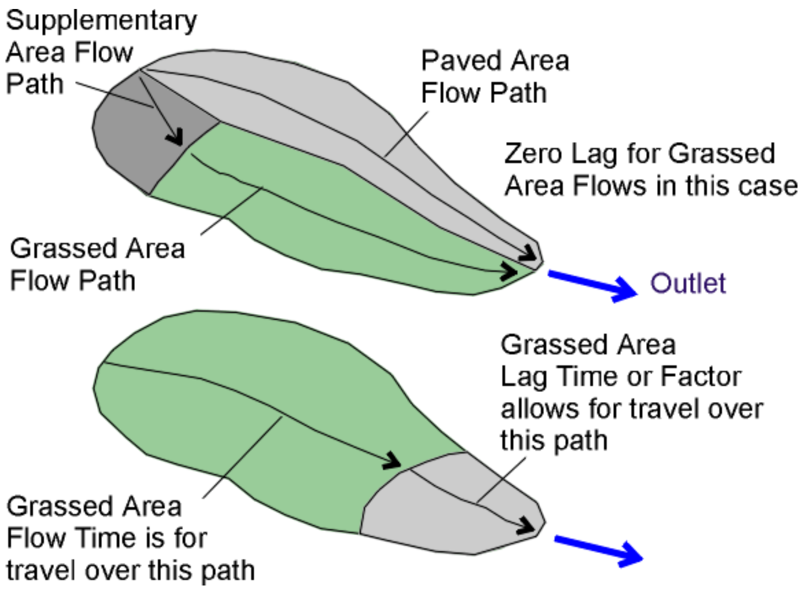


Figure 2.19 Explanation of Lags

(b) Rational Method Sub-Catchments

The property sheet has a very similar format to the ILSAX model sub-catchment property sheet, the main difference being that sub-catchments are being divided into pervious and impervious areas, instead of paved, supplementary and grassed. An example is shown in Figure 2.20.

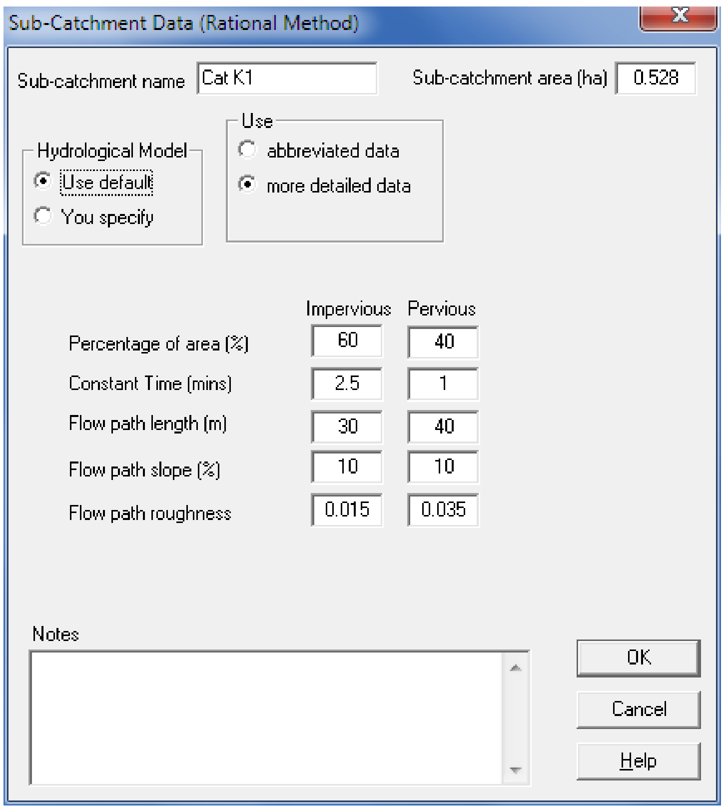


Figure 2.20 Rational Method Sub-Catchment Property Sheet

The sheet is similar for the three available types of rational method model (General, Australian Rainfall and Runoff, 1987, and Standards Australia AS/NZS 3500.3:2003). The only difference is the need to enter roofed percentages for the AS/NZS 3500.3 method.

If a *DRAINS* model is converted to a rational method model, the paved and supplementary area percentages will be added to form the impervious area percentage. The impervious area constant time will be the paved area constant time and the pervious area constant time will be the grassed area constant time. With the current version of *DRAINS*, no adjustments are made for supplementary area times or for grassed area lag factors. If allowance is to be made it will have to be done for each sub-catchment individually.

(c) Extended Rational Method Sub-Catchments

The property sheet used is the same as that for the rational method, as shown in Figure 2.20.

(d) Storage Routing Model Sub-Catchments

The three storage routing model described in Section 5.4, RORB, RAFTS and WBNM, require different inputs, due to their different structures and parameters.

Figure 2.21 shows a RORB sub-catchment input. Since no routing calculations occur in a RORB sub-catchment in *DRAINS*, only the sub-catchment area and impervious area percentage are required.

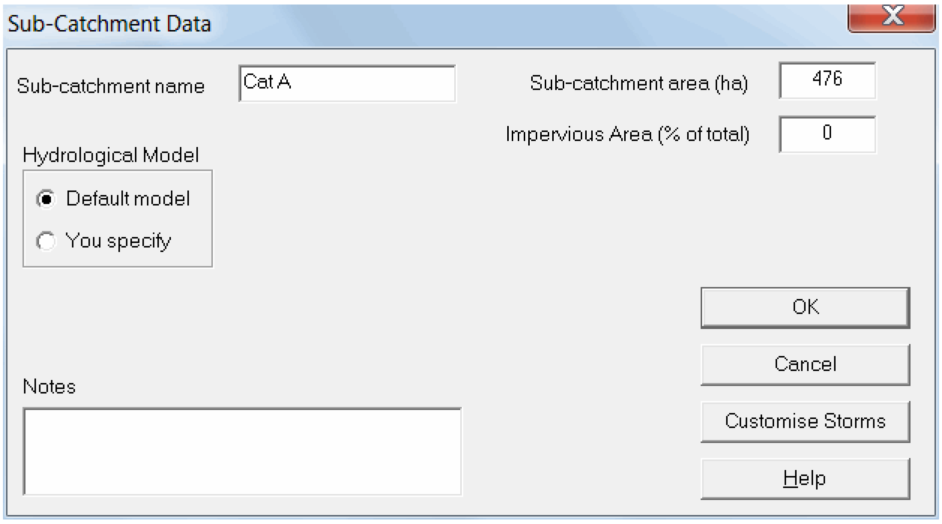


Figure 2.21 RORB Model Sub-Catchment Property Sheet

The sheet for a RAFTS sub-catchment shown in Figure 2.22 requires more information. In addition to catchment area and percentage impervious, a sub-catchment slope and a Manning's n for the pervious portion of the catchment are required to calculate hydrological losses and to define a routing parameter.

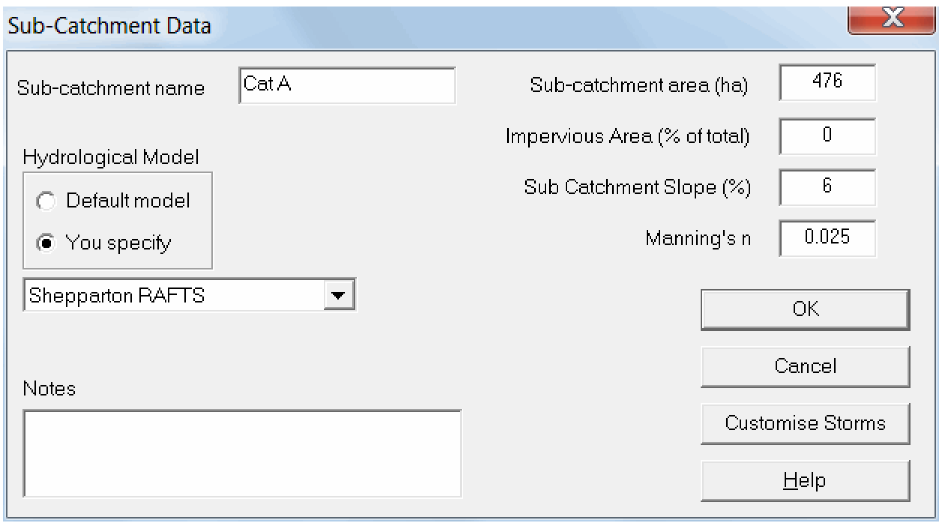


Figure 2.22 RAFTS Model Sub-Catchment Property Sheet

The property sheet for the Watershed Bounded Network Model (WBNM), shown in Figure 2.23, is the same as that for the RORB Model. However, routing does occur in WBNM sub-catchments, using equations based on the sub-catchment area.

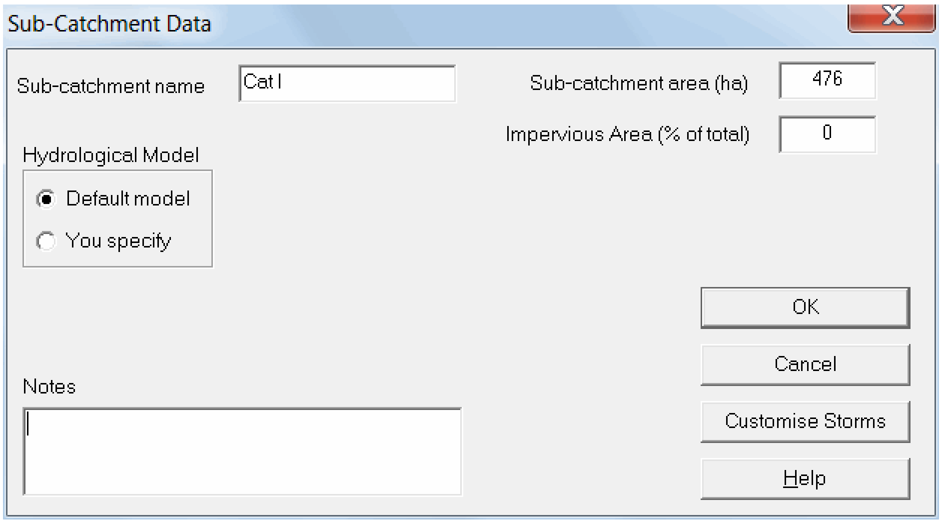


Figure 2.23 WBNM Model Sub-Catchment Property Sheet

(e) Customising Storms

The **Customise Storms** button near the bottom of the ILSAX model Sub-Catchment property sheet allows special features to be chosen, using the property sheet shown in Figure 2.24. These features are useful in special studies involving gauged rainfall and flow data, or where you wish to explore the effects of varying the rainfall intensity, pattern and timing of storms over the catchment area.

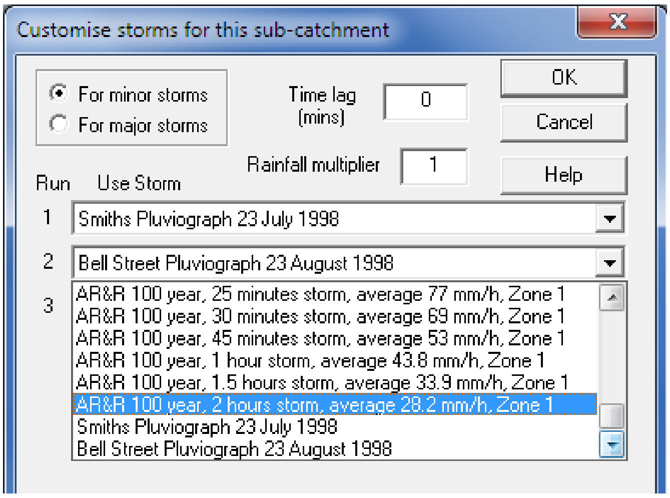


Figure 2.24 Property Sheet for Customising Storms

You can select a particular storm to apply to this sub-catchment, in Design or Analysis calculations. The storm is selected from the rainfall pattern data base using the list box shown. A time lag can also be specified and the storm patterns can be multiplied by a constant rainfall multiplier. These allow for the following situations:

- Areally-varying intensities across a catchment with the same storm pattern can be modelled by setting up a rainfall pattern in the Storm Data Base for each intensity used and selecting appropriate ones for each sub-catchment. A simpler alternative is to set a suitable multiplier for each sub-catchment in the property sheet shown in Figure 2.24.
- Varying storm patterns across a catchment can be modelled in the same way, by selecting patterns from the data base that apply to each sub-catchment, and applying multipliers if necessary.
- A moving storm can be described by specifying different lag times for the start of the storm for each sub-catchment.

These options allow you to specify a different rainfall pattern and intensity at every sub-catchment in a drainage network. They can be used to model climate change effects.

2.3.6 Overflow Routes

(a) General

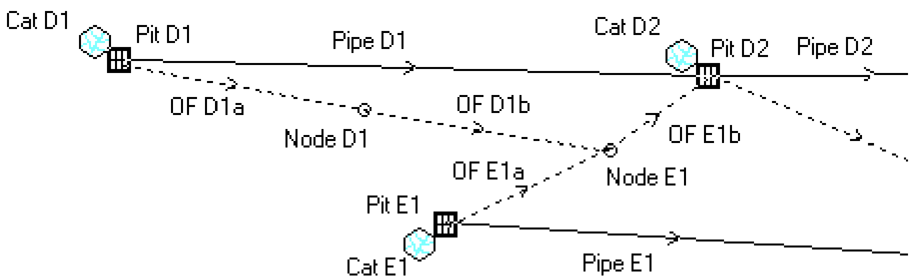
These paths define the routes taken by stormwater flows that bypass on-grade pits and/or overflow from pressurised pipe systems. *DRAINS* uses this information to calculate flow characteristics along the routes. The property sheet takes different forms depending on the hydraulic model being enabled. Three different routing processes may be involved:

(a) translation (shifting of a hydrograph by a time lag without changing its shape), employed in the standard and obsolete basic hydraulic calculations,

(b) kinematic wave calculations, employed in stream routing channels with RAFTS storage routing calculations,

(c) full unsteady flow modelling, employed in premium hydraulic model calculations.

Overflow routes between pits or nodes can be divided into a number of overflow route segments, separated by nodes. They can also combine at a node, as shown below:



A path made of two or more segments can have differing cross-sections, slopes, etc. In premium hydraulic model calculations *DRAINS* traces a HGL through these segments, defining a backwater curve on mild slopes.

(b) Basic and Standard Hydraulic Model Inputs

With the standard or obsolete basic hydraulic models, clicking on an overflow route opens a two- or three-page property sheet . As shown in Figure 2.25, all that is required on the **Basic Data** page is a name and an estimated time of travel,. During calculations, any overflow hydrographs will be delayed by this time of travel. The information on the second, **Cross Section Data** page, which is the same for all hydraulic models, is described in Section (e).

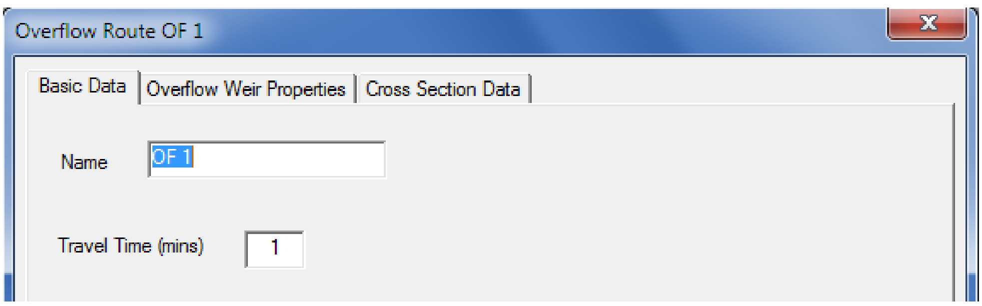


Figure 2.25 First Page of the Overflow Route Property Sheet (Top Portion)

(c) Premium Hydraulic Model Inputs

If premium hydraulic model calculations are enabled, the first page of the property sheet should have the form shown in Figure 2.26. Rather than specifying a travel time, the length of the overflow route and invert levels at each end of the flow path are required. *DRAINS* uses this with information from the **Cross Section Data** page to route flows along the route.

If an overflow route leaves a sag pit, you must also specify control weir information in a third, **Overflow Weir Properties** page of the overflow route property sheet, shown in Figure 2.27

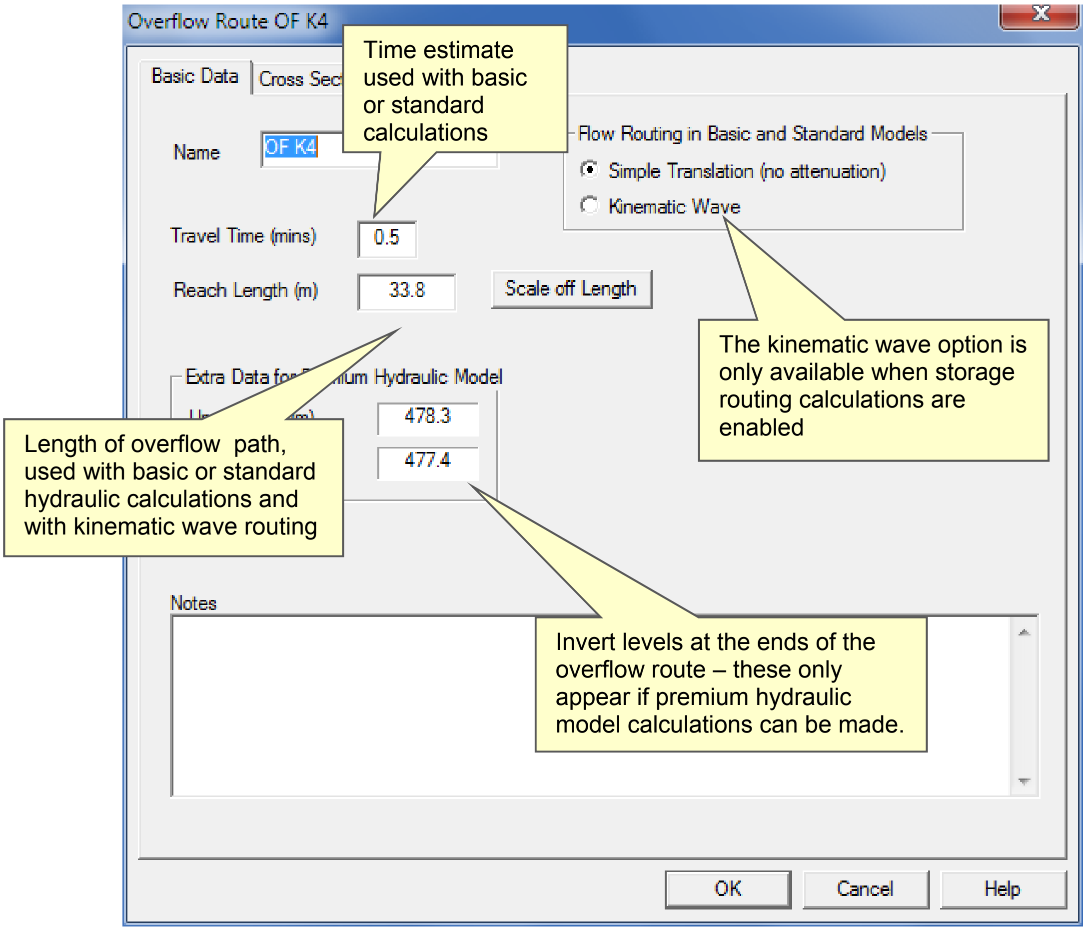


Figure 2.26 First Page of Property Sheet for Premium Hydraulic Model Calculations

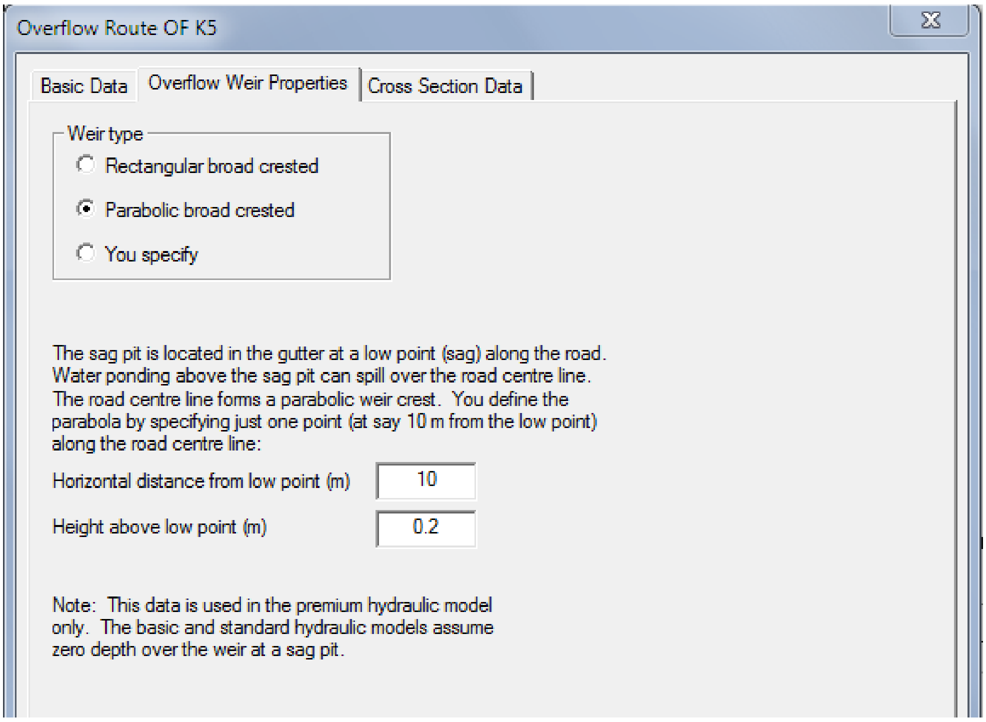


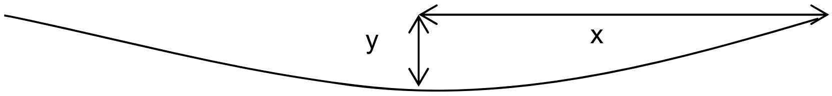
Figure 2.27 Weir Properties Page in Overflow Route Property Sheet

This is to provide a hydraulic control representing a barrier such as the crown of a road or an entrance to a property. There are three choices on the page:

- a rectangular weir,
- a parabolic weir representing a vertical road alignment, and

- a general depth-discharge relationship that can be set up on a spreadsheet and transferred to *DRAINS*.

The rectangular weir requires a weir width (the coefficient is taken to be 1.7); the parabolic relationship requires a depth at a given distance from the low point (as shown below), while the elevation-discharge relationship is more general.



Since the premium hydraulic model must deal with potentially very high flowrates in 100 year ARI and PMP storms, it models situations where there are chains of storages and overflow routes. The storages are likely to be at sag pits, but can also occur at ponding locations that are created in large storms. The overflow routes connect the storages. Both storages and overflow routes can be small or extensive.

A typical situation is shown in Figure 2.28. The overflow route will connect the ponded water on each side of the street. It will begin at the road crown and end at the downstream pit.

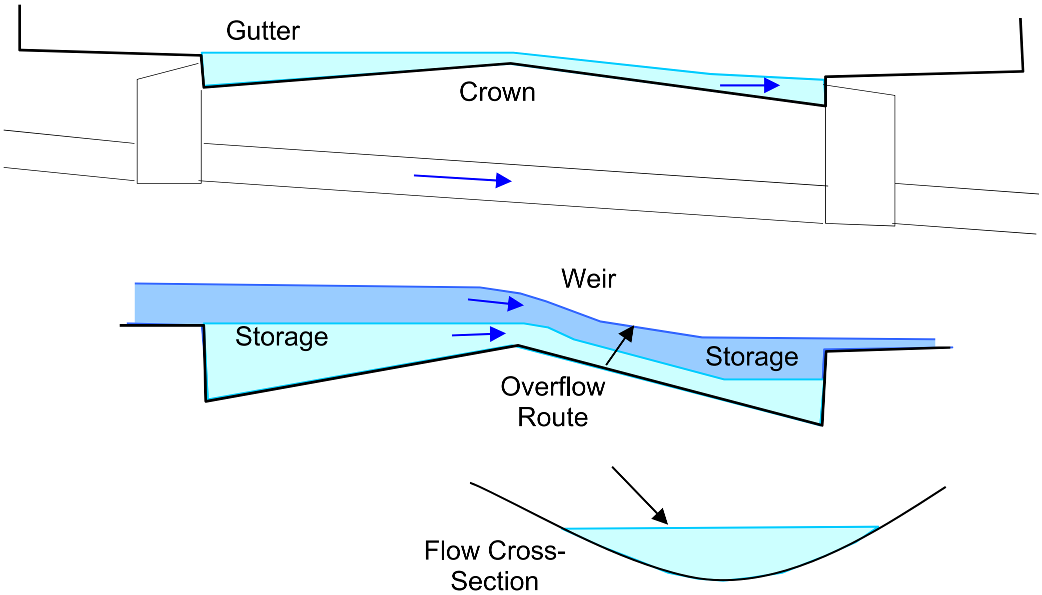


Figure 2.28 Flow Through a Road Low Point

During premium hydraulic model calculations, *DRAINS* will monitor the ponded levels in sag pits at each time interval. When the defined ponding level, assumed to be the level at which a spill will start to occur, is exceeded, overflow rates and ponding levels will be determined using the weir control specified in the overflow route property sheet (Figure 2.27). *DRAINS* will also calculate depths of flow in the overflow route and allow for a 'tailwater level' due to ponding downstream, if the overflow route terminates in a sag pit or detention basin. If the water level in the overflow route is greater than the weir crest level, the weir discharge will be reduced using a submerged weir equation, as described in Section 5.6.4.

It is important to establish pipe and overflow route levels and other details correctly. *DRAINS* provides a large number of checks to detect errors, but final responsibility for the accuracy of the model remains with the user.

(d) Kinematic Wave Routing Inputs

Overflow routes can also be used to model stream linkages in a RAFTS type of storage routing model, with the inputs shown in Figure 2.29. If this feature is enabled your hardware lock you can model urban overland flow paths using the kinematic wave routing procedure. While this has some advantages over the basic calculations for overflow routes from pits, the best procedure is to employ the premium hydraulic model if this is available.

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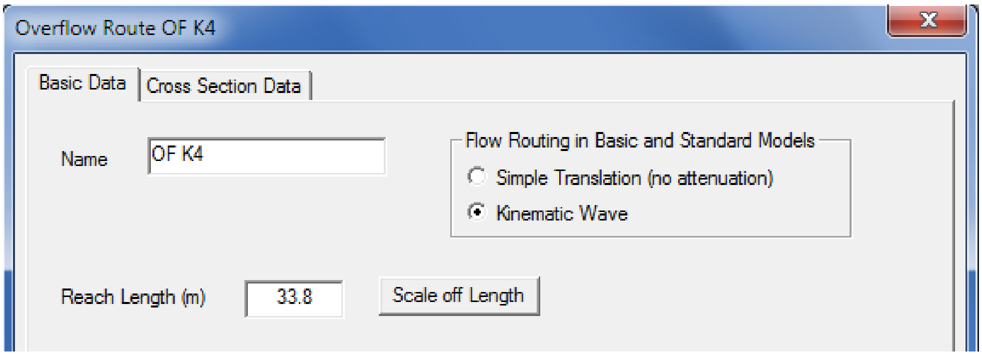


Figure 2.29 First Page of the Overflow Route Property Sheet with Kinematic Wave Routing
(Top Portion)

(e) Definition of the Flow Cross Section

On the second page, you should specify an overflow path cross-section from the Data Base set up in the **Project** menu, described in Section 2.4.7. The section may be a roadway, as shown in Figure 2.30, or a trapezoidal, rectangular or other channel shape.
.

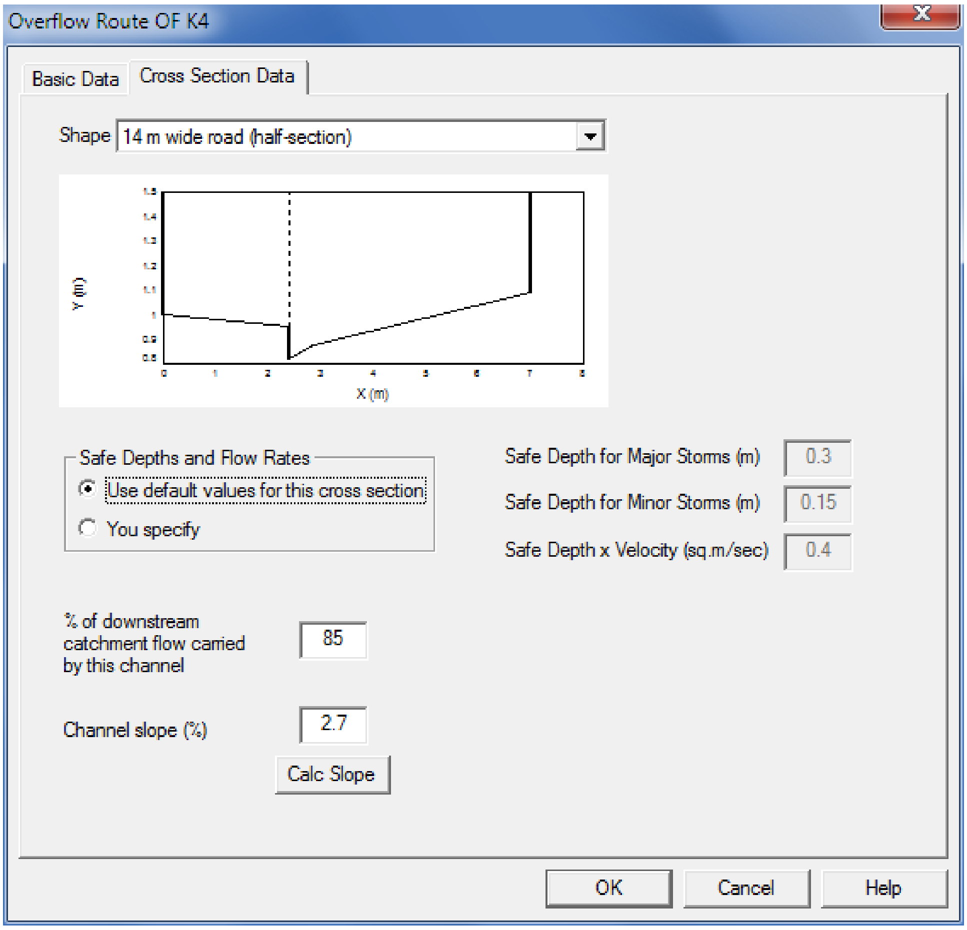


Figure 2.30 Cross-Section Data Entry in Overflow Path Property Sheet

Here it is necessary to select:

(a) a shape from the list box,

(b) the percentage of flows estimated to come from the downstream sub-catchment, and

(c) a flow path channel slope.

(With the storage routing model option shown in Figure 2.29, *DRAINS* uses the cross-section in its kinematic wave calculations. In both procedures, it will calculate flow characteristics such as depths and widths, assuming that normal depth occurs in the flow cross-section at the slope indicated.)

DRAINS can define flow characteristics at a selected critical location, which may be at a pit receiving overflows from this overflow route, combined with flows from its local sub-catchment. This location could also be just downstream of the pit from which the overflow occurs. The position is effectively defined by the percentage of the downstream catchment's flow that is carried by the cross-section, which must be entered into the property sheet in Figure 2.30.

Figure 2.31 shows how a downstream sub-catchment may contribute to flows. Here the critical point is the downstream pit, which is in a sag. An estimated 65% of Catchment 2 drains to this point, on the left side of Pit 2.

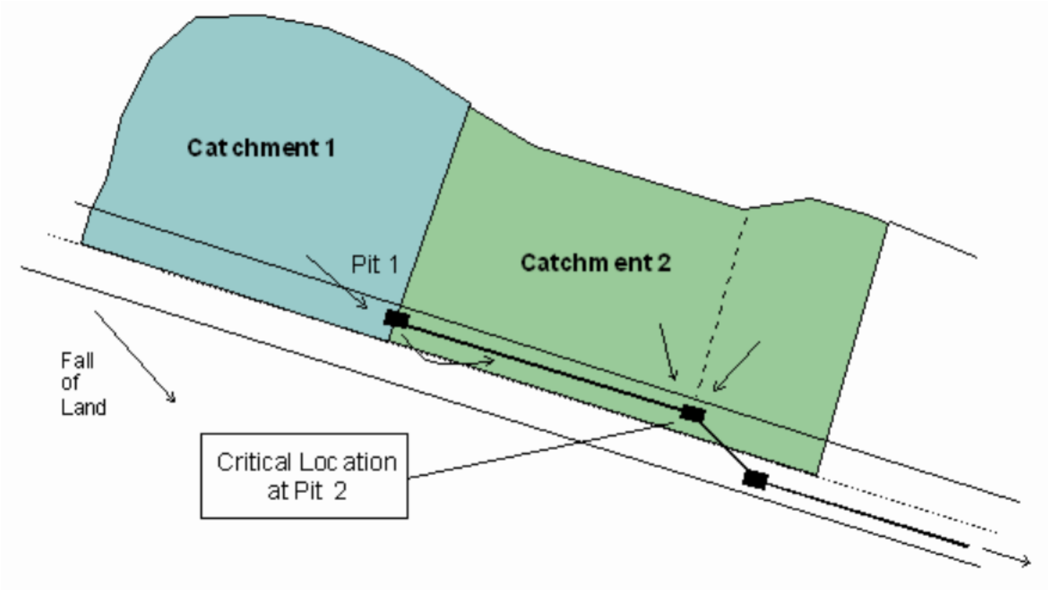
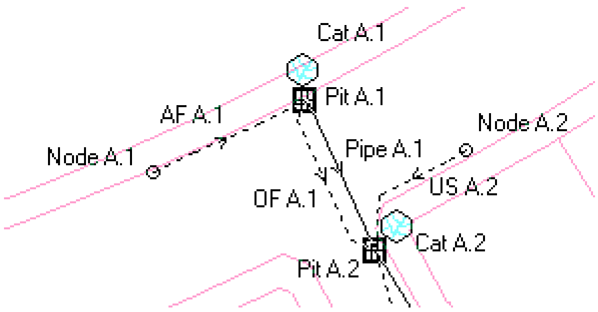


Figure 2.31 Effect of a Lower Sub-Catchment upon Overflows

If the property sheet for the overflow between Pit 1 and Pit 2 specifies a percentage of downstream catchment of 0%, the flowrate displayed in the results will be the overflow from Pit 1. This applies to a point just below Pit 1. If the percentage is set at 65%, the flowrate displayed will be the overflow from Pit 1 plus 65% of the flow from Catchment 2. This sum is calculated from addition of hydrographs, and represents the flow at a point just upstream of Pit 2. By varying the specified percentage between 0% and 65%, we can define surface flows at any point along the flow path.

Using this feature, you can examine the flows approaching pits at the top of a pipeline, as shown below.



Although the overflow routes originate from a node with no connected sub-catchment, a percentage of the flows from sub-catchment Cat A.1 can be specified and the flow characteristics along the flow path determined.
When applying the Design procedure, *DRAINS* focuses upon the flow at the point defined by the specified percentage of the downstream catchment. This can represent a critical feature such as a child care centre or bus stop that needs to be specially protected. (Note that this feature will only be meaningful on long overflow routes. The flows calculated will not be accurate for short flow paths where the calculated normal depth cannot be established and paths across streets or around corners.)

By changing the value in the box labelled 'Channel slope (%)', the slope can be varied along the entire flow path length to reflect a concave or convex longitudinal profile, as opposed to a constant slope.

Overflow routes can be divided into several segments, linked through simple nodes. These segments can have different properties such as cross-sections and slopes. Two or more overflow routes can be connected to a node, and their flows combined, as shown later in **Error! Reference source not found.**.

As described in the next section, the overflow path from a detention basin acts as a high-level outlet to the basin, and requires additional information to an overflow from a pit, this being set out on an additional page of the property sheet.

2.3.7 Detention Basins

DRAINS can incorporate large or small detention and retention basins into drainage networks. To define a basin or storage fully, at least two components are required. The first is the basin, which is defined in the Detention Basin property sheet, an example of which is shown in Figure 2.32. This includes a basin name, options to set an initial water level and infiltration characteristics, an elevation-surface area (or elevation-volume) relationship, and a low level outlet specification.

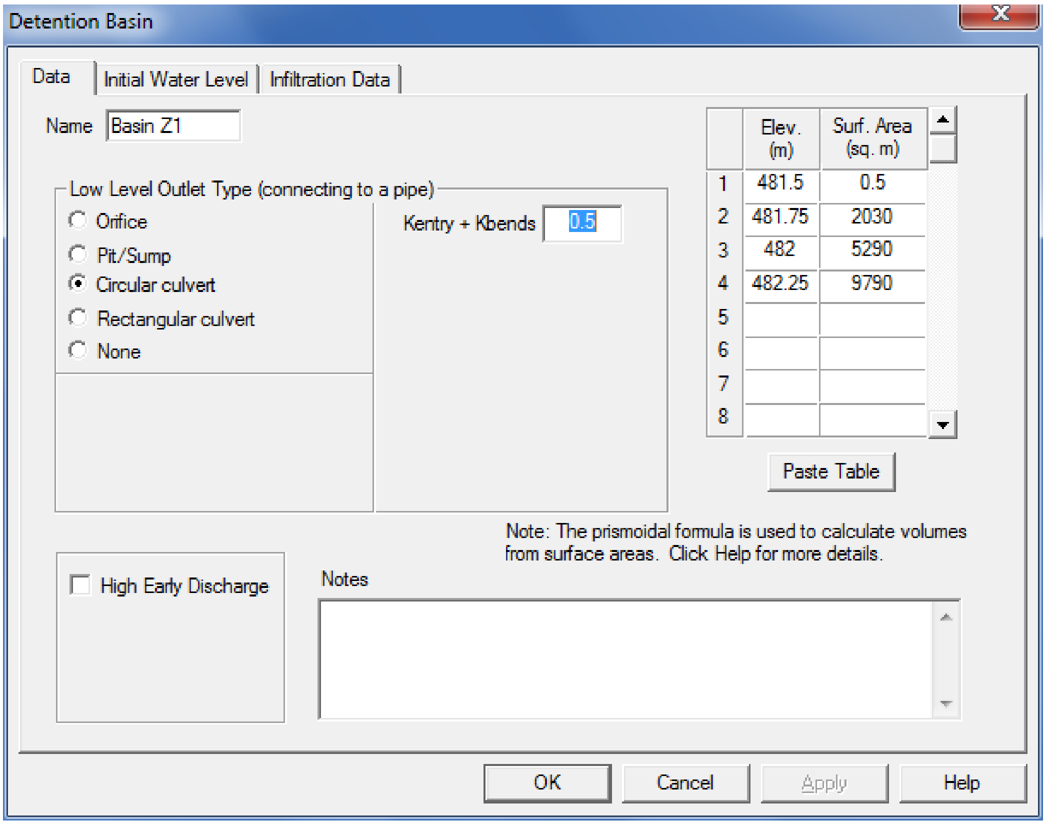


Figure 2.32 Detention Basin Property Sheet

DRAINS applies as a default an elevation-surface area relationship rather than an elevation-storage volume relationship, which will be easier for users, since volumes are calculated from surface areas in most cases. Previously-developed models that specify volumes, shown in Figure 2.33, are still supported in *DRAINS*, but both types of elevation-based relationship cannot be used in the same model. Elevation-volume relationships can be used in projects by selecting an option in the **Project Options** property sheet opened from the **Project** menu.

When working with elevation-surface area relationships, *DRAINS* employs an interpolation procedure for calculating volumes corresponding to certain elevations, with a fitted curve rather than the set of straight-line segments. The elevation-surface area relationship must use levels to the same datum as the rest of the drainage network. Relationships can be calculated in a spread-sheet and pasted into *DRAINS* Using the **Paste Table** button. Numbers must be arranged into two columns, as shown to the right.

700.5	0
701.1	1275
701.4	6170
701.7	17760
701.8	19000
701.9	20000
712	22000

These are then selected and the **Edit** → **Copy** option is used to place the data on the clipboard. Transferring from the spreadsheet program to *DRAINS*, the data can be entered using the **Paste Table** button.

The Low Level Outlet Type (connecting to a pipe) option buttons offer five choices:

- an orifice acting as a free outfall of the type commonly used in on-site stormwater detention (OSD) storages in Sydney;

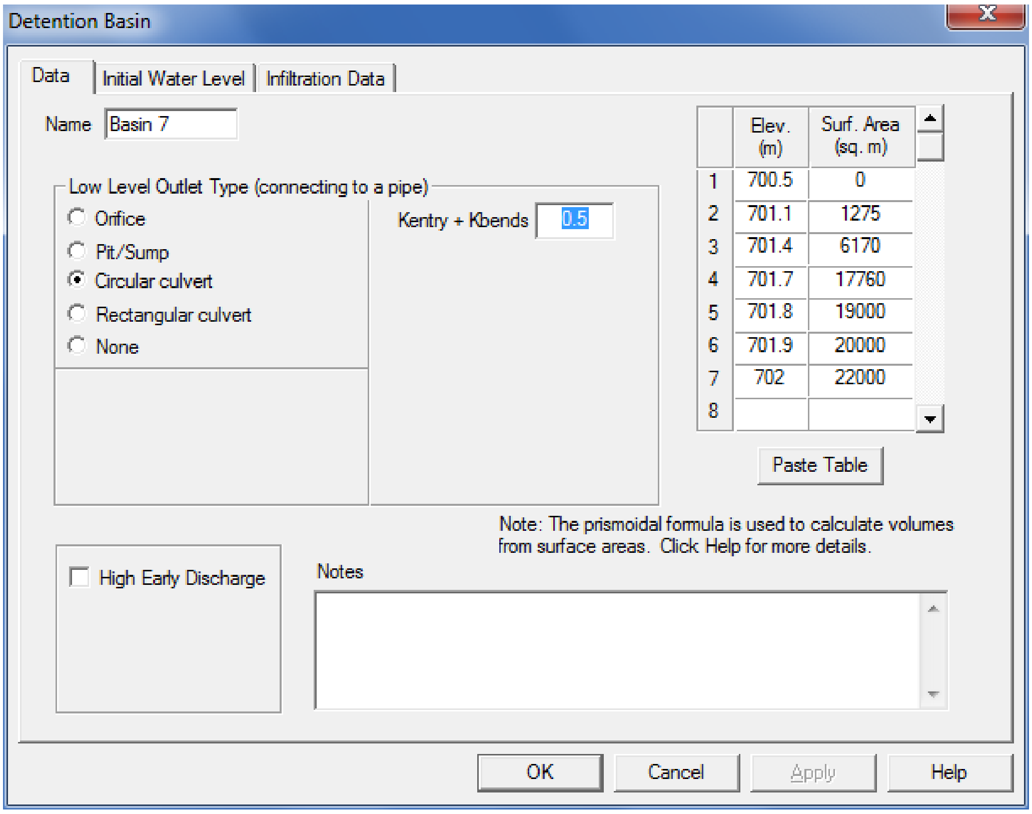
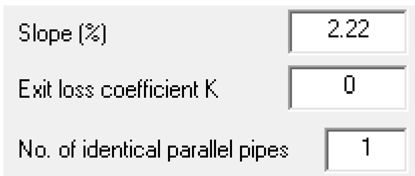


Figure 2.33 Detention Basin Property Sheet with Elevation-Storage Relationship

- a pit or sump outlet;
- a circular conduit (the example shown above);
- a rectangular channel, similar to the circular outlet; and
- no low-level outlet.

These are then selected and the **Edit** → **Copy** option is used to place the data on the clipboard. Transferring from the spreadsheet program to *DRAINS*, the data can be entered using the **Paste Table** button.

For pipes, it is only necessary to specify the entry and bend losses, as shown in Figure 2.32. The rest of the information is included in the property sheet for the outlet pipe. This is the same as the sheet for a pipe located between pits, as shown in Figure 2.12 , except that there is provision for an exit loss different from the loss of 0.0 assumed by *DRAINS*.



If an orifice outlet is selected, the property sheet takes the form shown in Figure 2.34. You must supply a diameter (mm) for a circular orifice, and the elevation of its centre. The check box labelled High Early Discharge allows the modelling of a high early discharge pit, a special type of OSD system. You must provide a crest level and length for an internal weir that is a feature of this kind of storage. Further details of these options are given in Section 5.8.3.

The pit/sump outlet type may apply in situations where basins are created unintentionally by the creation of a barrier such as a road embankment. If this outlet type is selected, the outlet changes to that shown in Figure 2.35. A pit family and size is to be selected using the same drop-down list box as in the Drainage Pit property sheet.

Since this type of outlet is prone to instabilities in calculations where there are incoming pipes that are below the surface of the basin, it is usually necessary to locate the basin 'off-line', connecting to a sealed pit through a large, artificial pipe with a capacity well in excess of the inlet. An arrangement of this type is shown in Figure 2.36. Surface overflows are directed to the basin, and the main overflow comes out of it. The pipe leaving a basin is specified in the same way as a normal pipe. If this is rectangular, it may be necessary to set up a special pipe type and size in the Pipe Data Base, as described in Section 2.4.5.

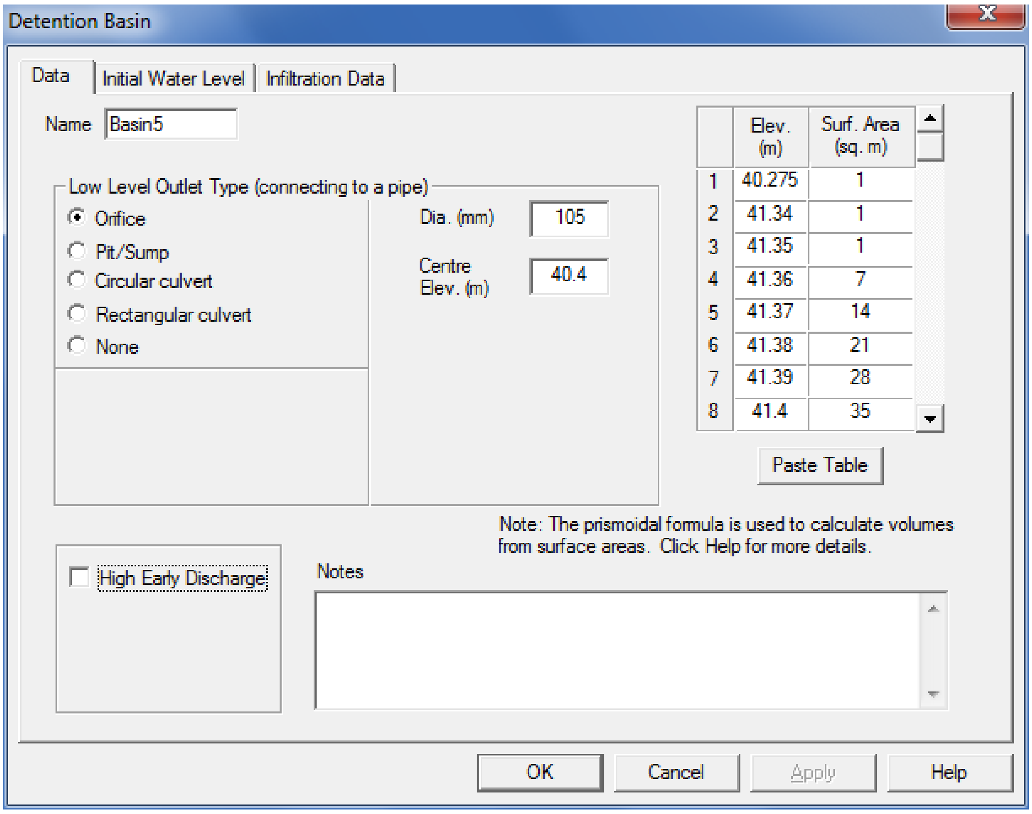


Figure 2.34 Detention Basin Property Sheet with Orifice Outlet

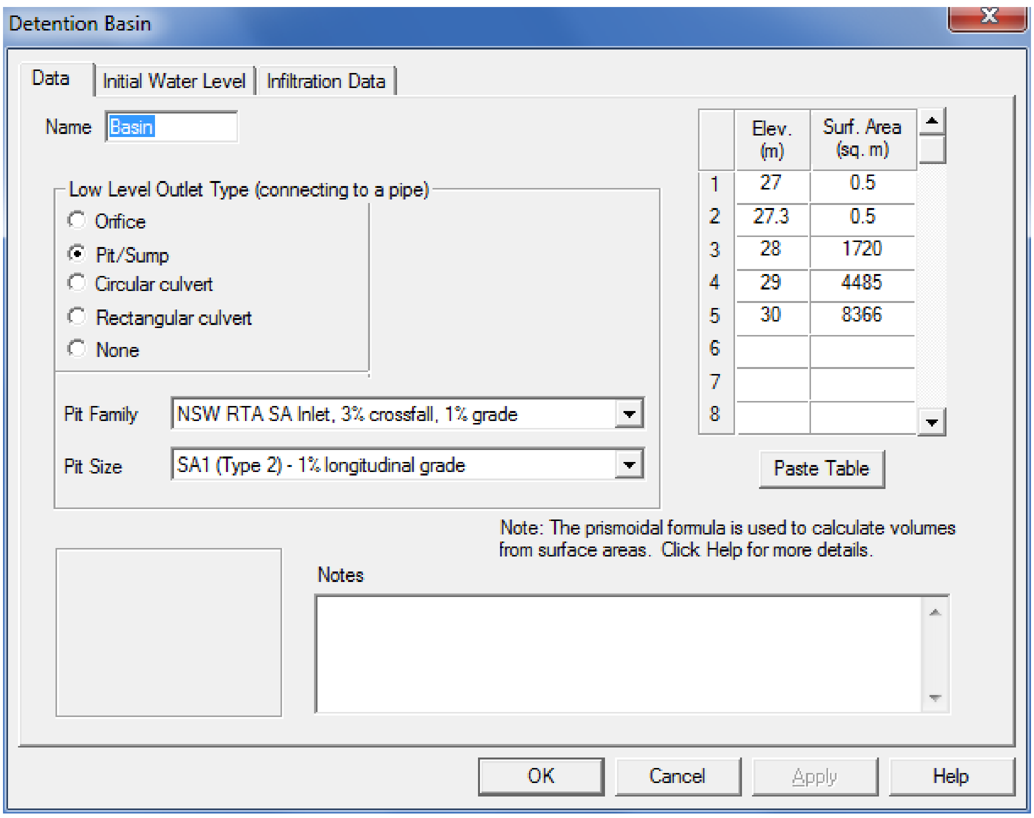


Figure 2.35 Detention Basin Property Sheet for a Pit/Sump Outlet

For some basins in low-lying areas where backflows may occur, a non-return valve may be specified in the Pipe property sheet. Only one low level pipe can exit from a detention basin, with specified invert levels. The required size and invert levels cannot by determined in Design runs, but must be established by trial and error using analysis runs.

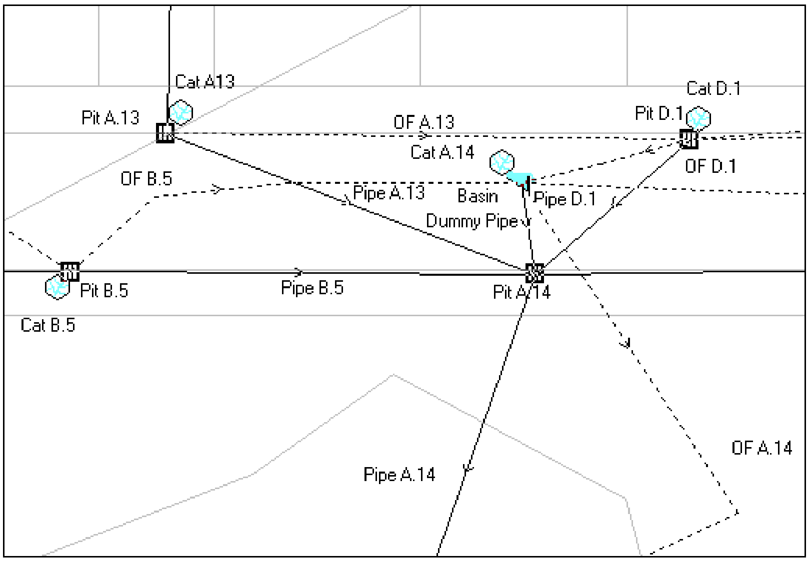


Figure 2.36 Arrangement for a Basin with a Pit/Sump Outlet

Where the 'basin' is a ponding area in a street with a sag pit that acts as an unintended storage, the above method can be used with the standard hydraulic model. If the premium hydraulic model is available, this pit should be modelled as a sag pit with a table of elevation-area values describing the storage.

The fifth and last type of outlet is a **'None'** option. If this is selected, water can only leave the basin through a high-level outlet (to be described below), and the outflows will not be affected by downstream hydraulic grade lines or backwater effects. If a height-outflow relationship is specified for a high level outlet, the detention basin modelling will be carried out in the relatively simple way used in ILSAX, rather than having HGLs projected upwards through the basin.

A new development is the provision of an in-built infiltration calculation facility on the second page of the Detention Basin property sheet. This appears as shown in Figure 2.37.

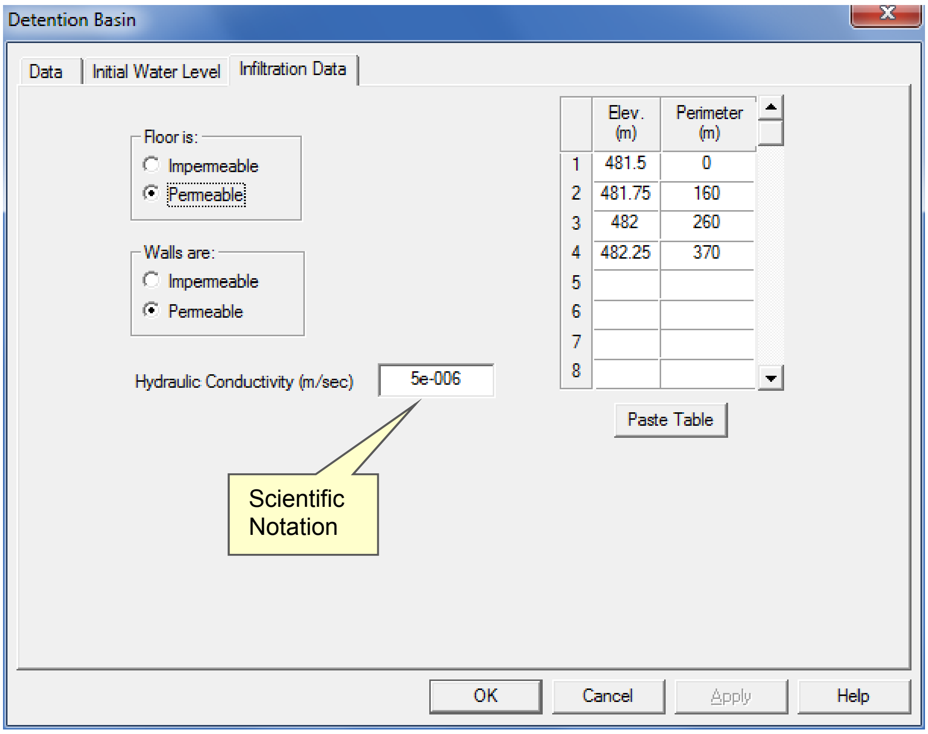
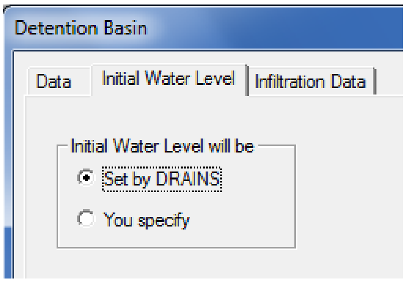


Figure 2.37 Infiltration Data Specification

Allowance is made for a flat floor, as provided in infiltration chambers and trenches, and for walls through which infiltration will occur when the stored water level rises above the floor level. The perimeter of the walls at different elevations can be defined in the table. The hydraulic conductivity depends on the type of strata through while infiltration occurs. Further information is provided in Argue (2004). Conductivities

are quite small and in most cases need to be specified in scientific notation. For example, a conductivity of 2×10^{-6} m/s can be specified as '2e-6'. *DRAINS* specifies these as 2e-006.



The page on the Detention Basin property sheet tagged 'Initial Water Level', shown to the right, can be used to make a basin part-full at the start of a storm. Usually it is assumed that the basin is empty. (Use of this facility may result in some reverse flows at the start of a storm,)

The last component required to define a detention storage is the high level outlet, which is described in the property sheet for the overflow route from a basin. When an overflow route originates in a basin, the property sheet has three pages instead of the two shown in Figure 2.25 and Figure 2.30. Two of these pages are the same as those in those figures. On the third page, labelled 'Weir Data' you have the choice of specifying a weir outlet, as shown in Figure 2.38, or an elevation-discharge (or height-outflow) relationship, as shown in Figure 2.39.

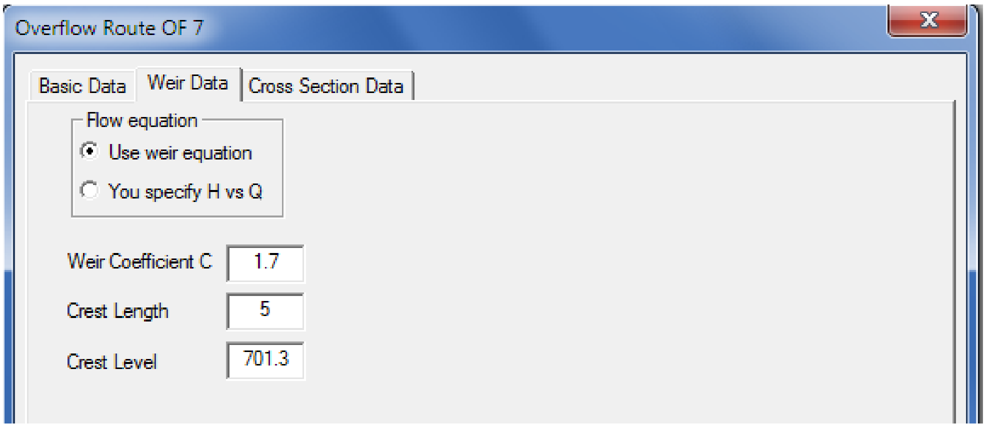


Figure 2.38 Outlet Definition of a Weir (Top Portion of Page)

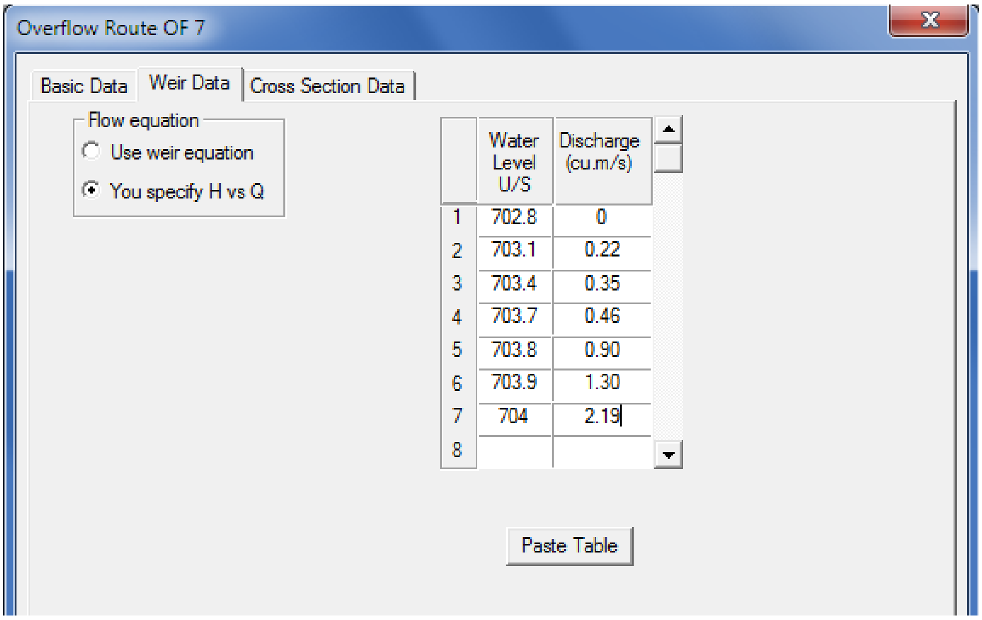


Figure 2.39 Elevation-Discharge Table for a High-Level Outflow (Top Portion)

For a weir, you must provide a weir coefficient, a width (m) (at right angles to the direction of flow) and a crest level (m). Further details are given in Section 5.8.2. A suitable coefficient for the earth embankments used as high-level outlets for many detention basins is 1.7.

If used alone, the elevation-discharge relationship must be determined using equations relating to both the low and high level outlets. If it is certain that no backwater effect can submerge the outlets, this relationship will be constant. As noted earlier, if '**None**' is specified for the low level outlet in the Detention Basin property sheet and an elevation-discharge relationship is given in the Overflow Route property sheet, a simplified basin routing can be applied.

There can be any number of overflow routes from a basin, representing high level outlets at various levels. Pumped discharges and stormwater infiltration can be modelled using overflow routes with suitable water level - discharge relationships, but it is best to use the specific pumping and infiltration methods provided.

Elevation-discharge relationships can be calculated in a spreadsheet and pasted into the Overflow Route property sheet using the **Paste Table** button in Figure 2.39.

2.3.8 Special Weirs and Orifices

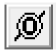
Two new components in *DRAINS*, the orifice,  and the weir , are only available with the premium hydraulic model. These facilitate the modelling of complex detention basins that have multiple orifice or weir outlets that can connect to various outlet points with different tailwater levels. With the standard hydraulic model, it is possible to model a single pipe or orifice-controlled outlet and multiple weirs that are located above tailwater influences. However, it is difficult to model a second pipe or orifice even when this leads to a free outfall. The new components make such modelling easy and accurate under complex tailwater conditions.

Figure 2.40 shows an example named **`Premium Detention Basin.drn`** that has two orifice and two weir outlets. The orifice and weir links can be bent or kinked to allow several links to go to a common point. This can be done by clicking on the link, so the ‘handles’ appear at the ends, placing the mouse pointer on the line, holding down the mouse button, and moving the pointer.

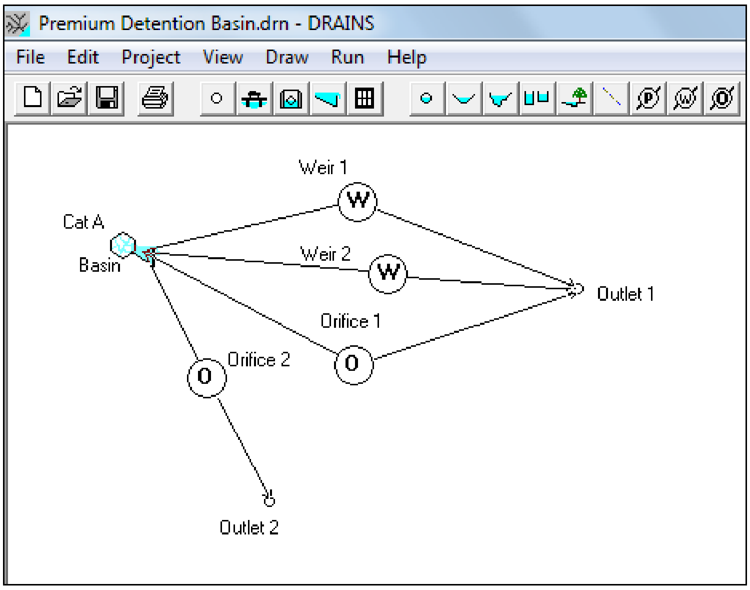


Figure 2.40 Detention Basin with Special Orifice and Weir Outlets

The property sheets for the Orifice and weir are shown in Figure 2.41.

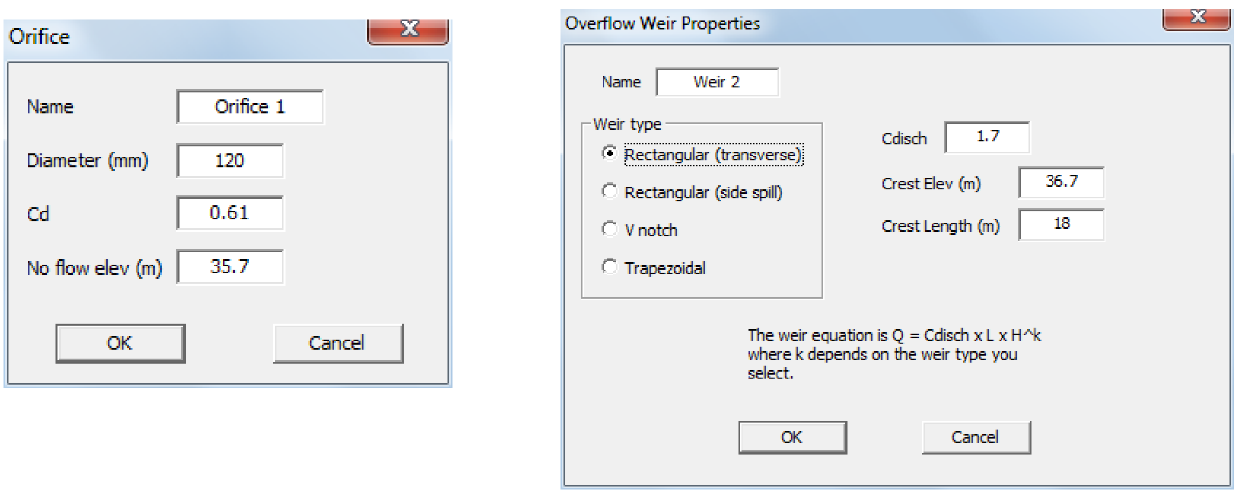


Figure 2.41 Special Orifice and Weir Property Sheets

2.3.9 Pumps

As described in the previous section, pumps can be modelled with an overflow route coming out of a detention basin. Howe However, this can cause problems when applying the premium hydraulic model, and a specific pumping link has been provided.

When the tool  is selected a pump link  can be drawn. This must come out of a detention basin and can be directed to a pit, a simple node or another detention basin. The associated property sheet, shown in Figure 2.42, requires a level at which the pump switches on and off (relative to the water level in the basin out of which it comes), and a table of water elevation vs. flowrate.

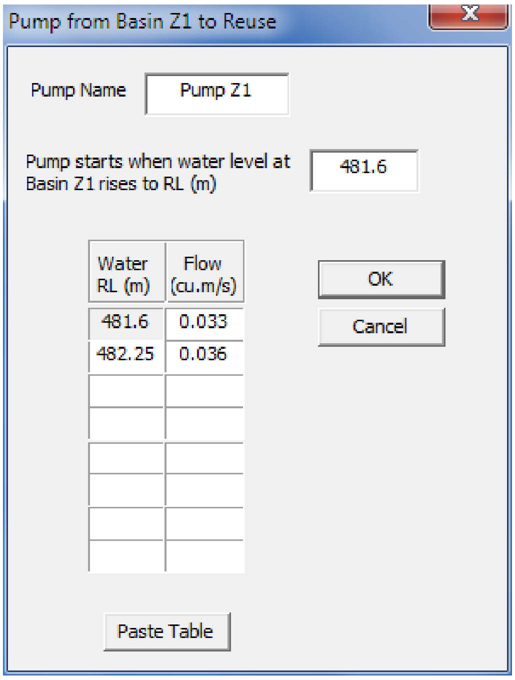


Figure 2.42 Specification of a Pump from a Detention Basin

The pump starts operating when the storage water level rises above 222.0 m. The pump rate increases from 160 to 300 L/s as the water level rises to 223.5 m, reflecting the characteristic head versus discharge relationship for the pump and the friction and shock losses through the delivery pipe. A worksheet in the *DRAINS Utility Spreadsheet* (Section 3.2.3) can assist in developing an appropriate pumping relationship, which can be imported into the Pump property sheet using the **Paste Table** button.

Pump links can be bent of kinked, like those for special orifices and weirs.

2.3.10 Prismatic Open Channels

The Prismatic Open Channel property sheet, shown in Figure 2.43, enables easy entry of the parameters needed to define trapezoidal. Rectangular or triangular channels of uniform cross-section and slope. (Rectangular channels have zero side-slope factors, and triangular channels have a zero base width.)

If calculations determine that the channel depth exceeds that specified in this property sheet, the sides of the channel will be extrapolated upwards, and a warning message will be provided. *DRAINS* does not allow for overflows from channels. In the majority of cases, where overflows will follow the same route as the main stream channel, they can be accommodated by defining a channel cross-section large enough to carry them. If necessary, the channel should be defined as an irregular open channel, as explained in the following section, to include overbank flow areas.

Where an overflow from a channel will cause a breakout that follows a different path to the main stream, special ways of modelling the separation of flows are required (see Table 2.2 in Section 2.3.17).

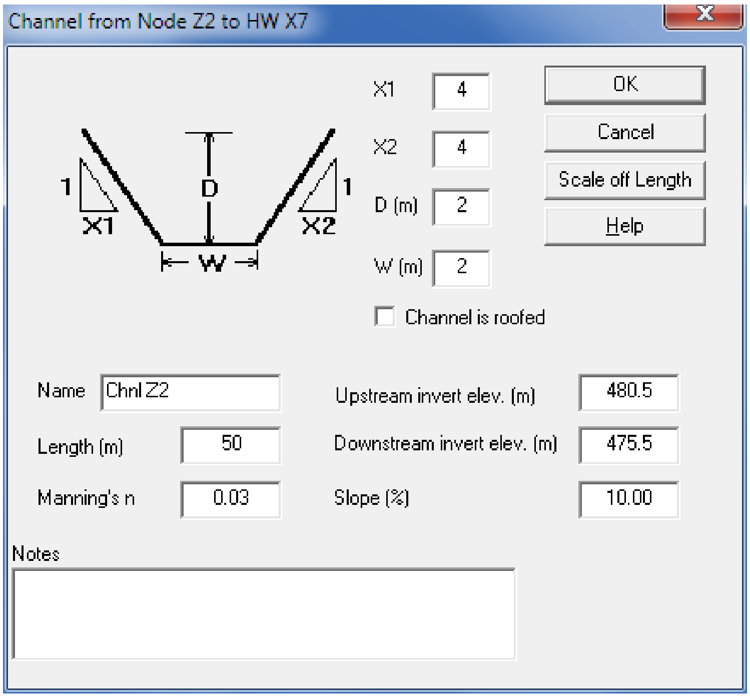


Figure 2.43 Prismatic Open Channel Property Sheet

2.3.11 Irregular Open Channels

(a) General

This component, with the property sheet in Figure 2.44, allows you to set up stream reaches to model a stream or channel with varying cross-sections and slopes.

It can also be used to model closed and open conduits with cross-sections other than circular, rectangular or trapezoidal.

The information required differs between the obsolete basic hydraulic models calculations and the unsteady flow calculations used in the standard and premium hydraulic models.

(b) Basic Hydraulic Model Calculations

It is necessary to define channel reaches over which flowrates are the same, and to define for each reach at least two cross-sections, at the upstream and downstream ends of the reach. At each cross-section, you must enter:

- the channel name, total length and chainages or lengths of reaches along a stream; a set of X-Y coordinates (m) that define the cross-section, with the X datum being at an arbitrary point on the left bank of a channel, and the Y datum being Australian Height Datum (AHD) or some other standard datum (as shown in Figure 2.45).
- distances from the upstream node (m) and Manning's roughnesses for the left overbank, main channel and right overbank areas;
- coordinate locations of the left and right banks (m), and expansion and contraction coefficients (dimensionless).

Various features assist the entry of cross-sections. Sections can be copied and pasted. The top section of a reach must be the same as the bottom section of the reach above it. If reaches are entered in a downwards direction, *DRAINS* automatically enters data from the previous reach. Sections can be viewed and checked using the **View Cross Sections** and **View maximum water level profile** options in the pop-up menu for an irregular channel component, as shown in Figure 2.46.

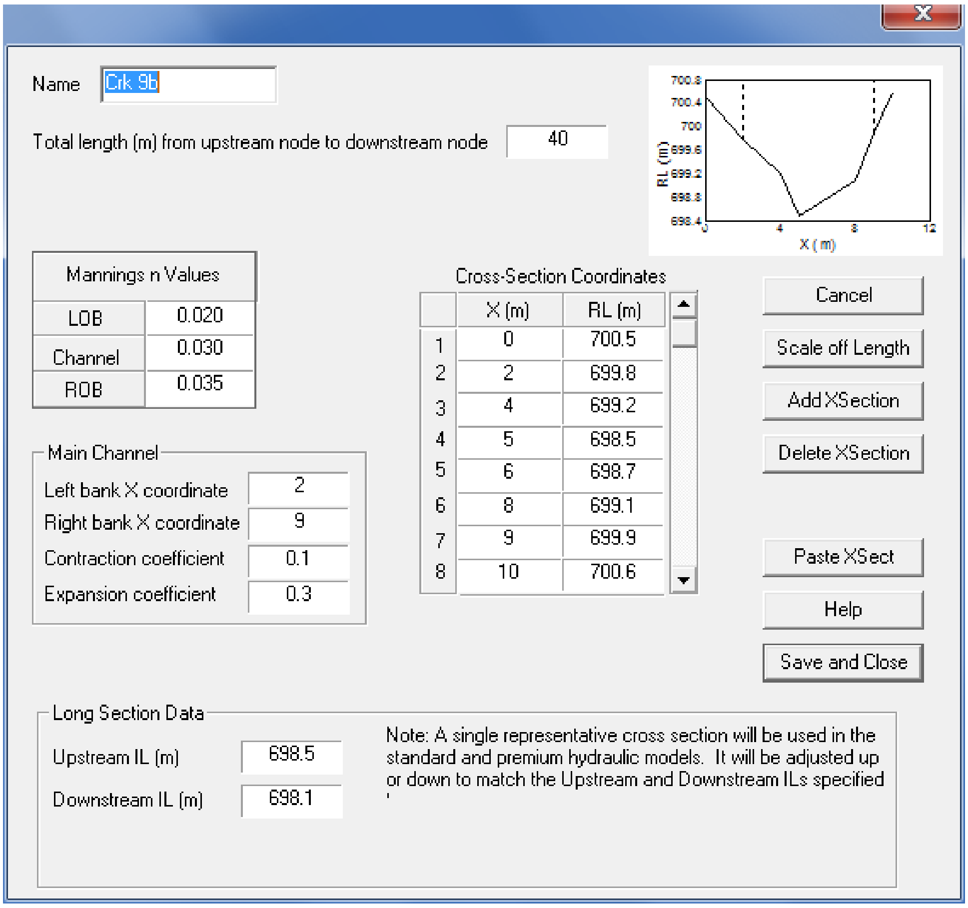


Figure 2.44 The Irregular Channel Property Sheet

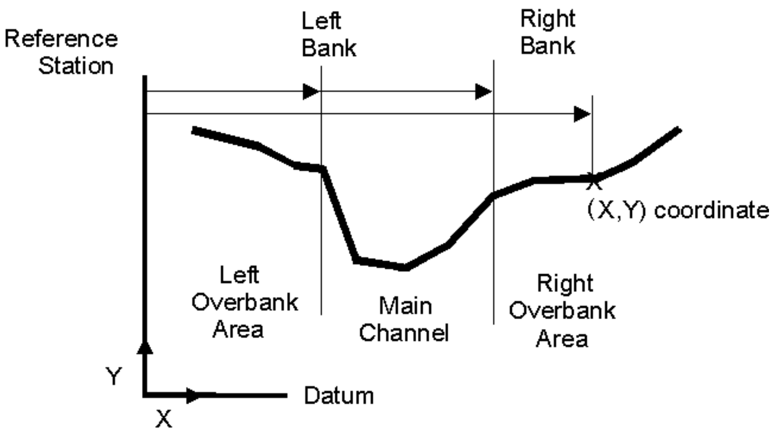
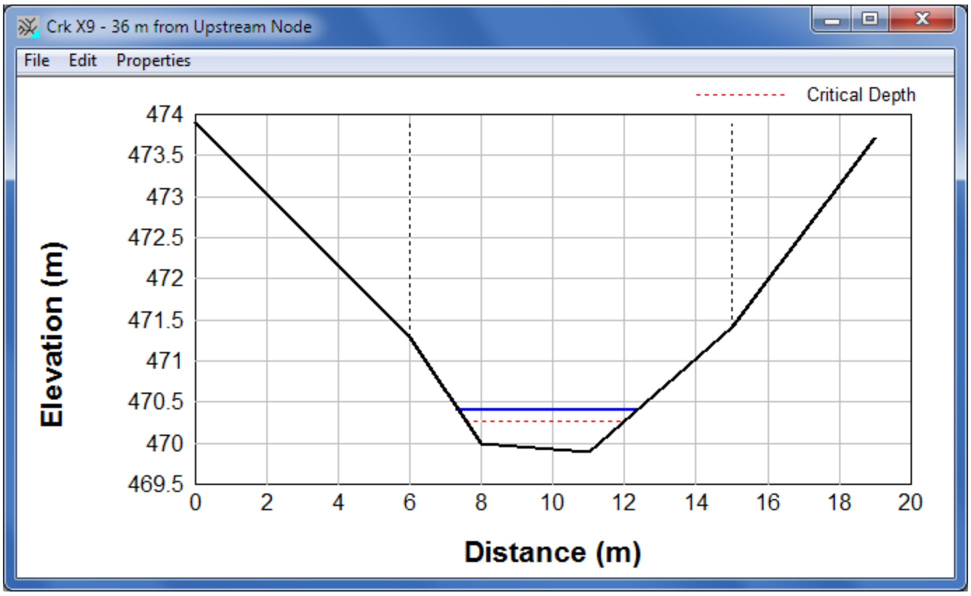


Figure 2.45 Coordinate System for Irregular Channel Cross-Section (looking downstream)

(c) Standard and Premium Hydraulic Model Calculations

The same inputs as those shown in Figure 2.44 are required, with the additional information specified at the bottom of the property sheet. The additional inputs are the invert levels at the upstream and downstream ends of the reach, and the number of the cross section to be considered as representative of the channel reach.

The two hydraulic calculation options use entirely different procedures. The basic method uses methods akin to the steady flow modelling carried out by the well-known HEC-RAS program (Hydrologic Engineering Center, US Army Corps of Engineers, 1997), in which cross-sections are required at each end of an irregular channel.



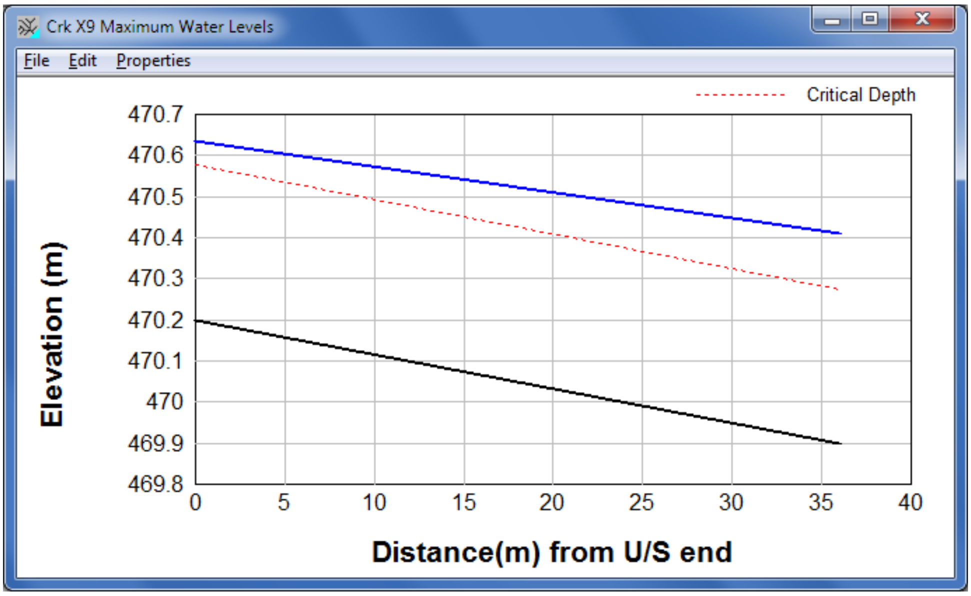


Figure 2.46 Irregular Channel Cross-Sections and Longitudinal Profiles

Like HEC-RAS, *DRAINS* allows cross-sections, roughnesses and bed slopes to vary along a channel, though it is not possible to change the flowrate along a channel. This can be done by specifying two or more irregular channels in series.

The unsteady calculations assume that each open channel has a constant cross-section and slope. This will suit lined channels well, but for natural channels, it may be necessary to define several sections of channel to allow for changes of cross-section.

2.3.12 Multi-Channels

The prismatic and irregular channel types do not adequately cover the situation where two or more channels with different characteristics connect the same two points. This is handled in the basic hydraulic calculations by multi-channels that use the property sheet shown in Figure 2.47 to call up the boxes for prismatic or irregular channels, or a box for circular channels.

The data required is similar to that for other open channels. Conduit lengths, roughnesses, slopes and even starting and ending levels can vary. *DRAINS* distributes flows between the different conduits. At present, *DRAINS* does not report on the separate flowrates.

Situations requiring multi-channels occur where inadequate open drainage systems are amplified by building a parallel channel or pipe, and where grassed floodway channels have a piped underdrain.

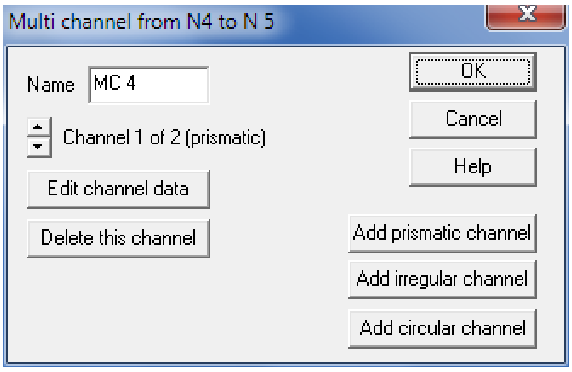


Figure 2.47 Multi-Channel Property Sheet

2.3.13 Stream Routing Reaches

This link type, shown as , is used with the RORB and WBNM storage routing models to connect nodes and sub-catchments as described in Section 5.4, and to perform non-linear routing. Its exact function differs between the two models as they have differing structures. (The RAFTS storage routing model describes stream reaches using the same overflow routes that were used for pipe systems, described in Section 2.3.6.)

If a RORB storage routing model is selected, the property sheet for its stream routing reaches appears as shown in Figure 2.48. A reach name and length must be specified, and a Channel condition selected. If a channel condition of 'excavated unlined' or 'lined or piped' are selected, it is also necessary to provide the reach slope.

The RAFTS stream channel property sheet, shown in Figure 2.49, is identical to that for an overflow route from a pit. A name is required, and if **Simple translation (no attenuation)** is chosen in the box labelled **Flow Routing Method**, a travel time through the reach must be entered. With a RAFTS model, this can be zero if a conservative result is required.

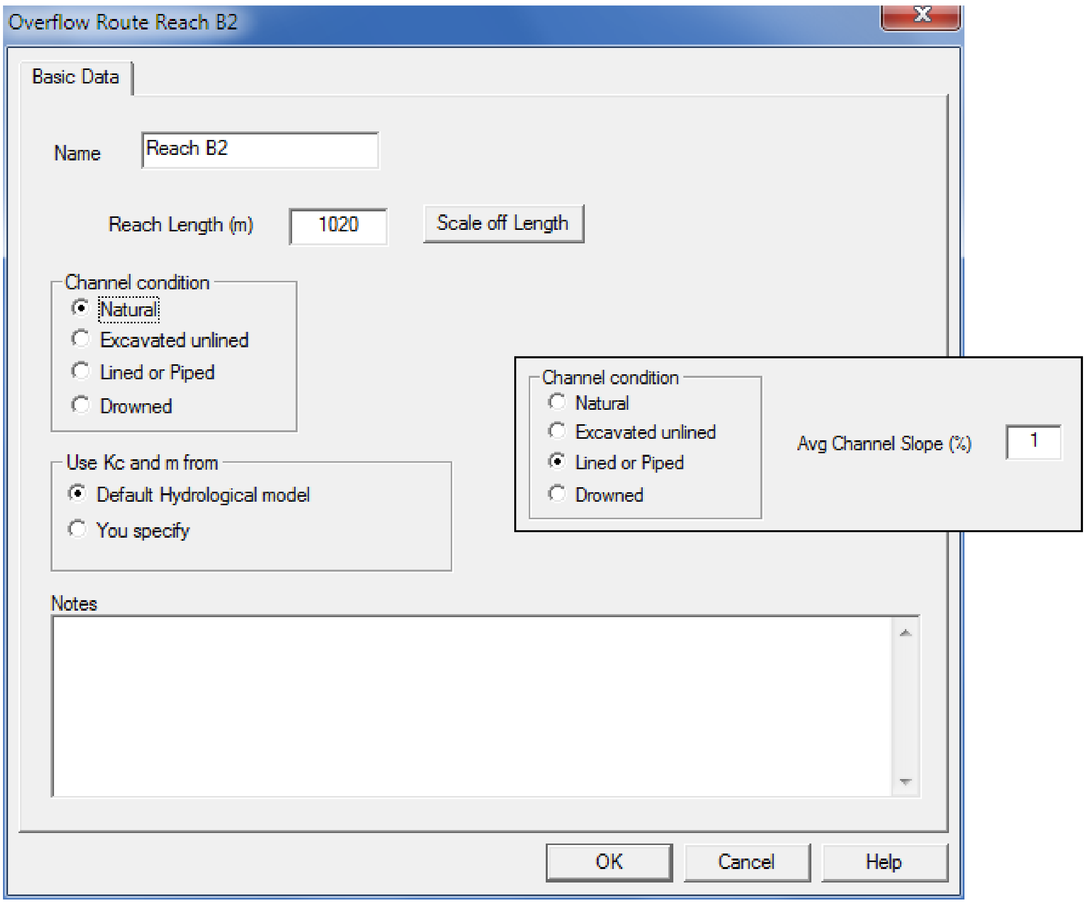


Figure 2.48 RORB Stream Routing Reach Property Sheet

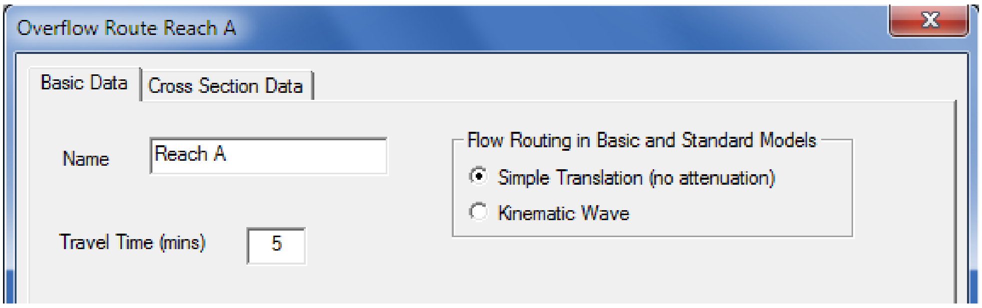


Figure 2.49 First Form of the RAFTS Stream Routing Reach Property Sheet (Top Part)

If the second option in the **Flow Routing Method** box is chosen, the property sheet changes to the form shown in Figure 2.50. It is now necessary to provide a reach length and, using the second page of the property sheet shown in Figure 2.51, a cross-section is to be selected from the Overflow Route Data Base. This section is meant to be representative of the whole stream reach and to be used in a kinematic wave routing procedure derived from Chapter 9 of *Open Channel Hydraulics* by F.M Henderson (1966).

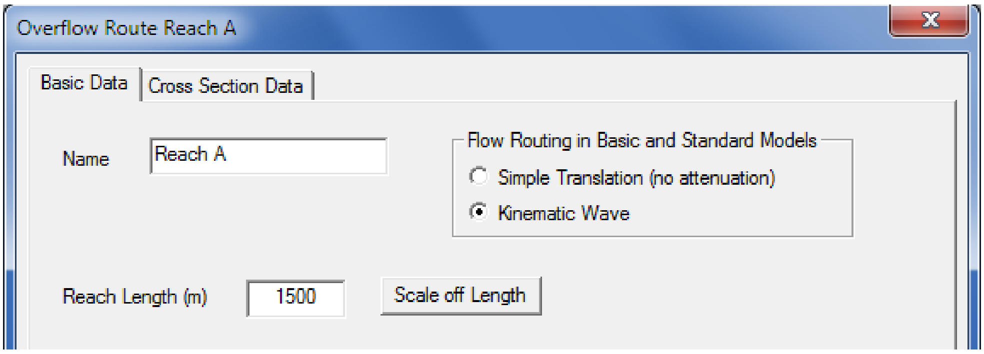


Figure 2.50 Second Form of the RAFTS Stream Routing Reach Property Sheet (Top Part)

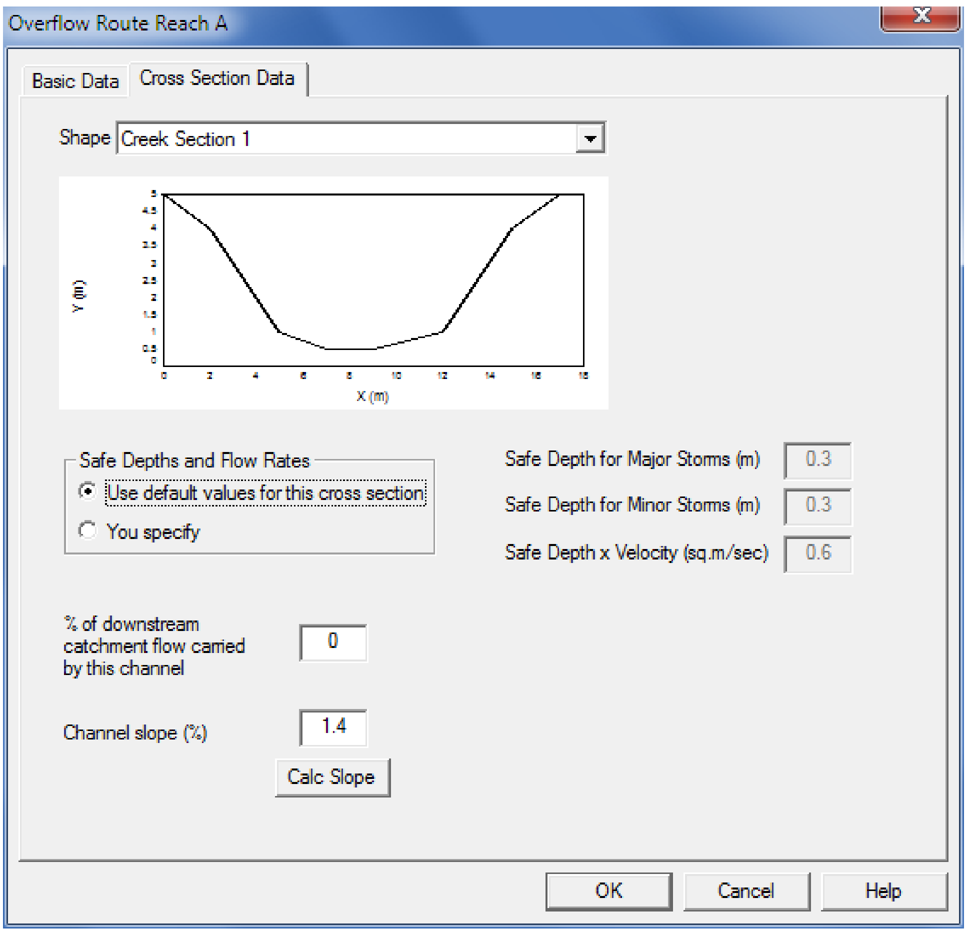


Figure 2.51 Second Page of the RAFTS Stream Routing Reach Property Sheet

When run, the kinematic wave option will produce two hydrographs, at the top and bottom ends of the reach, with a small reduction in peak flows. (As noted in Section 2.3.6, this specification can also be applied to conventional overflow routes in piped urban drainage systems, but the premium hydraulic model calculations are preferable.)

The WBNM stream routing reach property sheet shown in Figure 2.52 requires only a name and a stream lag factor. When this factor is not zero, routing occurs along the reach using parameters based on the area of the sub-catchment at the node at the end of the reach.

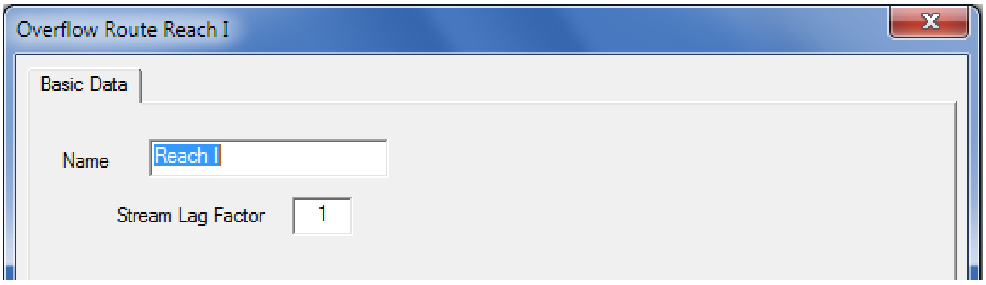


Figure 2.52 WBNM Stream Routing Reach Property Sheet (Top Portion)

2.3.14 Headwalls

The headwall  allows open channels to be connected directly into a pipe system, and overflows to be directed to other locations. It is not to be used as the outlet of a pipe system, which is modelled as a node. The Headwall property sheet is shown in Figure 2.53

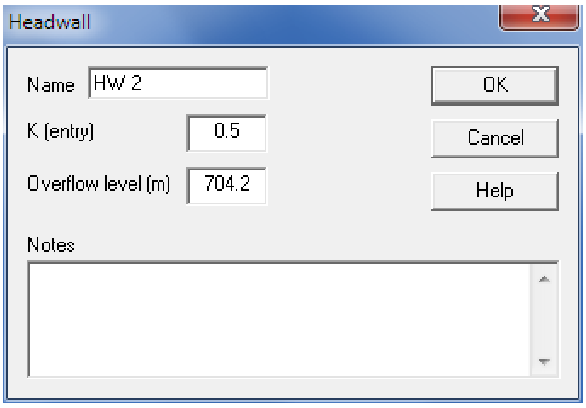


Figure 2.53 Headwall Property Sheet

The overflow level entered on this sheet is critical to the operation of this component at higher flows. As water levels increase to this level, the flow into the pipe is governed by the culvert equations described in Section 5.8.2. Once this level is reached, the inflow is assumed to be that corresponding to the nominated overflow level, while the headwater level (the level of the water level upstream) is assumed to be governed by the property sheet for the overflow route provided, which takes the form shown in Figure 2.38 and Figure 2.39. Assuming the overflow rate to be the upstream flowrate minus the pipe capacity, *DRAINS* calculates a flow depth based on the weir or elevation-discharge relationship, and adds this to the overflow level to obtain the headwater level.

This process will set a headwater level that is slightly conservative, as the depth of the overflow path flow is not considered in determining the flow through the pipe. This is necessary to avoid considerable iterative calculations caused by the splitting of the flows and the uncertainty of the effects of changing flowrates on the calculations for downstream pipes. An alternative way of handling this situation is by terminating an open channel at a detention basin and starting a pipe from there.

The headwall can be used to model culverts, as described in the next section.

2.3.15 Culverts

Initially, culverts were modelled in DRAINS using the Culvert component  the concentrated all the functions of culverts into a single object. This has now been replaced by the combination of a headwall with a pipe and overflow route, as shown in Figure 2.54, and the culvert object has been removed from the *DRAINS* Toolbar. This is similar to the arrangement used for detention basins.

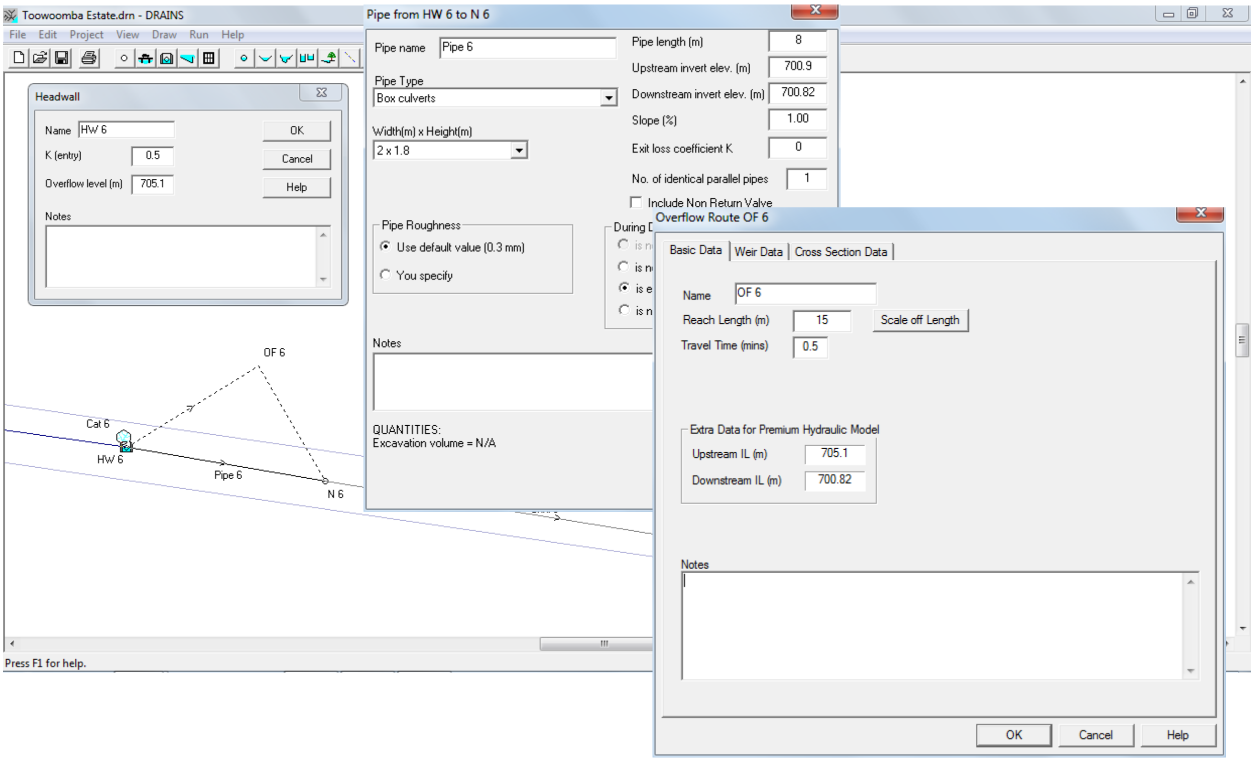


Figure 2.54 Culvert Constructed from Headwalls and Other Components

The inputs for these components are described in other parts of this chapter, while the inputs for the discontinued culvert object will be described in the Help System. If the obsolete culvert object has been used in an older *DRAINS* model, it will re-appear when this model is opened with the current version of *DRAINS*.

2.3.16 Bridges

The property sheet for Bridges is shown in Figure 2.55. Because of the differences in shapes, abutment and pier arrangements and approach conditions, bridges are more complex that culverts. In *DRAINS*, calculations are performed using a relatively-simple method provided in the AUSTROADS (1994) manual, which is based on the US Federal Highway Administration report by Bradley (1970). More complex bridge modelling procedures are available in HEC-RAS, MIKE-11 and other open channel hydraulics programs. *DRAINS* results should be checked using these programs if the accurate determination of levels is critical.

You will need to refer to the original references to understand the inputs required fully. It is necessary to specify:

- the name of the bridge, and the levels of the deck (m) and the soffit (underside of deck) (m);
- the weir coefficient for overflows over the bridge deck, typically 1.7;
- pier width, locations of piers (as noted in Figure 2.56), and pier type;
- the abutment type and the X-Y coordinates at the bridge section (m), left overbank, main channel and right overbank Manning's roughnesses, and the X locations of the left and right banks that divide the zones of different roughness (m).

With the standard and premium hydraulic models, the data shown in Figure 2.57 must be entered in the second page of the property sheet. This provides instructions on choosing the values to be entered.

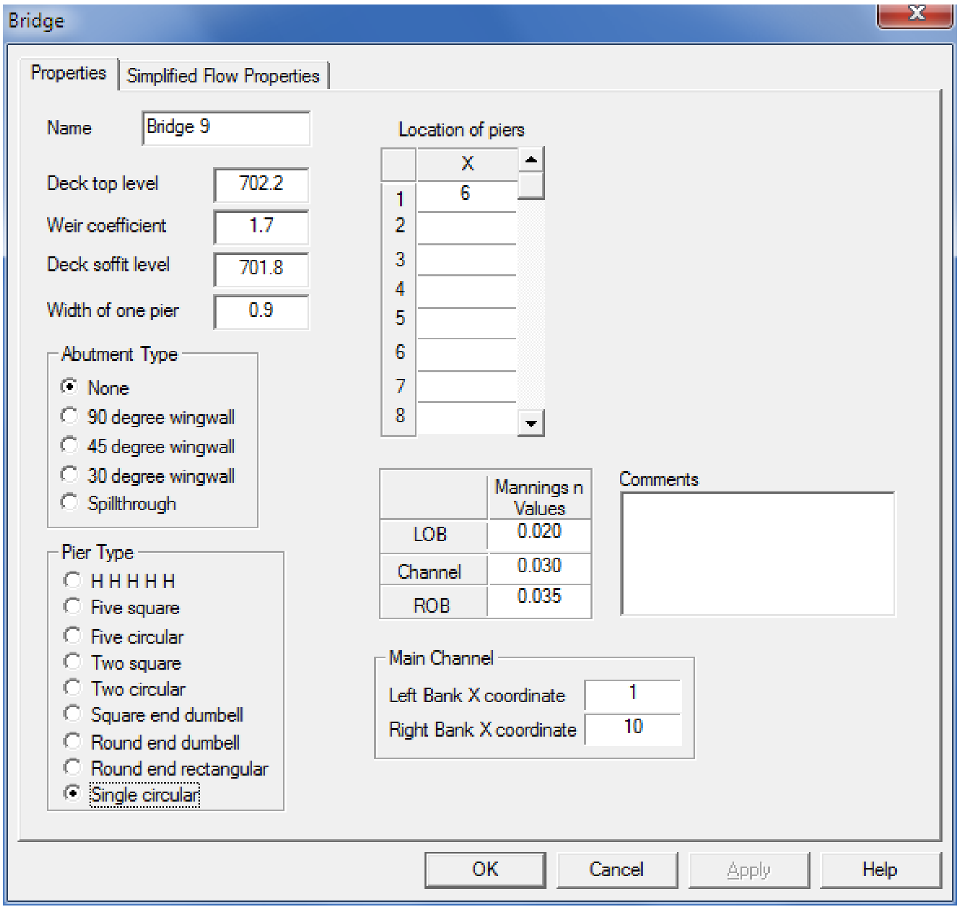


Figure 2.55 Bridge Property Sheet

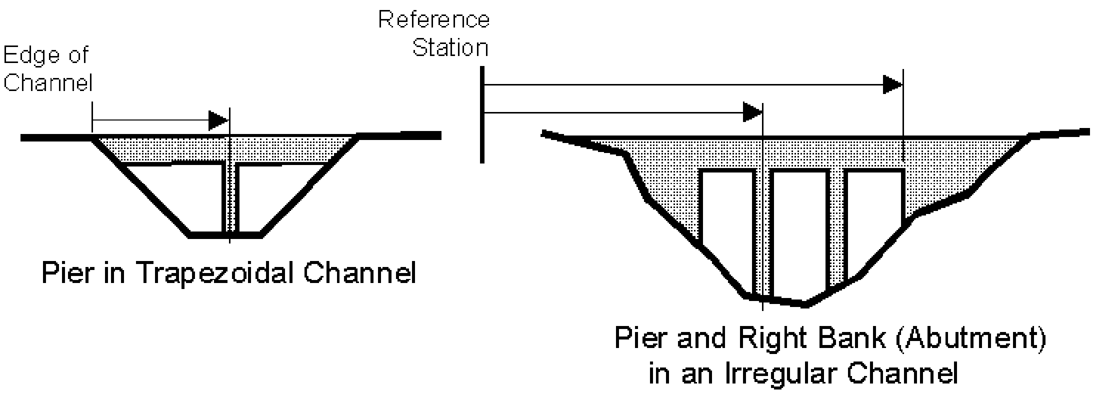


Figure 2.56 Pier and Abutment Locations

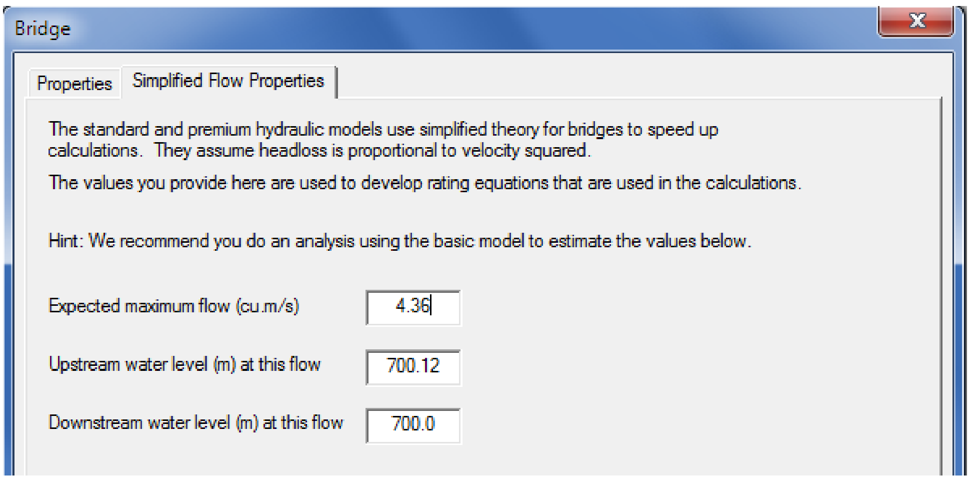


Figure 2.57 Second Page of Bridge Property Sheet (Top Part)

This information might be obtained by running the DRAINS model without a bridge to estimate the maximum flowrate, and inserting the bridge later. The upstream and downstream water levels can be estimated from the level without the bridge, making the upstream level higher and the downstream level lower. The differences might also be determined from relationships from texts or manuals.

2.3.17 Combining Components

Some arrangements of the components described in the preceding sections cannot be modelled because they are not logical, or they create computational difficulties.

Table 2.2 describes the possible connections between nodes and links noting those that cannot be made. The footnotes provide suggestions as to how you can get around some of these limitations. Experienced modellers can use dummy components to model complex situations.

Table 2.2 Allowable Connections between *DRAINS* Nodes and Links

Node	Link into Node from Upstream (U/S) or Downstream (D/S)				
	Pipe	Prismatic Channel	Irregular Channel	Multi-channel	Overflow Route
Simple Node	U/S - yes[1] D/S - yes[1]	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes[2] D/S - maybe[3]
Detention Basin	U/S - yes D/S - yes[4]	U/S - yes D/S - no	U/S - yes D/S - no	U/S - yes D/S - no	U/S - yes D/S - yes[5]
Headwall	U/S - no D/S - yes[4]	U/S - yes D/S - no	U/S - yes D/S - no	U/S - yes D/S - no	U/S - yes D/S - yes
Culvert object (obsolete)	U/S - no[6] D/S - no[6]	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes D/S - no[7]
Bridge[8]	U/S - no[6] D/S - no[6]	U/S - yes D/S - yes	U/S - yes D/S - yes	U/S - yes D/S – no[7]	U/S - yes D/S - no[7]
Pit	U/S - yes D/S - yes	U/S - no D/S – no[8]	U/S - no D/S – no[8]	U/S - no D/S – no[8]	U/S - yes D/S - yes

Notes:

1 - If a node has pipes both upstream and downstream, it acts as a closed junction, and can be pressurised, with the HGL rising above the surface. Generally, however, it is better to connect pipes through sealed or unsealed pits, where a head loss can be specified.

2 - You need to be aware that nodes will accept all flows coming to them, and check whether this is realistic. Where there are likely to be overflows, a pit should be substituted if the node is in a pipe system, and a detention basin if the node is in an open channel system.

3 - In the standard hydraulic model, overflows are permitted from a node, but not if there is also a pipe or channel leaving the node. For an open channel where overflows will run along the banks, you should raise the height of the channel cross-section so that overbank areas are included. The open channel downstream will need to be defined as an irregular open channel. Where channel overflows are to be directed out of a channel, you can place a detention basin at the location of the low point where overflows might occur, with an elevation-storage relationship based on the storage within the upstream channel. High-level outlets with weir data or a height-discharge table can be used to control the overflows. The premium hydraulic model allows a channel and overflow route to come out of the same node.

4 - Overflow links from a detention basin or headwall require more information than a normal overflow link, to define high level outlets. It is possible to have several high-level outlets from a basin.

5 - Culverts and bridges must have open channels or routing reaches upstream and downstream. Where a road is located at a point where stormwater emerges from a pipe, or goes from on open channel into a pipe, it is probably inappropriate to model this situation as a bridge or culvert. If cross-sections change under road in these circumstances, the transitions can be modelled by pipe or open channel sections.

6 - While water may pond behind a bridge or culvert, and even overflow over the top of the road, *DRAINS* does not allow for any diversion of flows away from the downstream channel. This might be modelled by locating a detention basin upstream of the device, or perhaps by modelling a culvert as a detention basin.

7 - Bridges have more restrictions than culverts in *DRAINS*. You cannot have two upstream channels meeting at a bridge, as they can at a culvert. It is necessary to insert a section of combined channel upstream of the bridge. A multi-channel cannot be placed downstream of a bridge - a short section of single channel can be interposed, however.

8 - You cannot have an open channel coming out of a pit. However, a short section of pipe and a simple node might be used to link the pit and a channel.

In a *DRAINS* Main Window, it is possible to have several, separate drainage systems. These may be completely independent, or may be connected by overflow links. When *DRAINS* runs, it applies the same rainfall and loss data to all systems, unless local options are selected in the **Hydrological Model** and **Customise Storms** options in the Sub-Catchment property sheet described in Section 2.3.5. This feature allows systems to be analysed together, to provide 'before' and 'after' comparisons.

The example file **`Sydney OSD.drn`** provides such a comparison for an on-site stormwater detention system. As shown in Figure 2.58, the pre-developed catchment is set out on the lower left, and the developed drainage system around a house and backyard occupies most of the window. These two systems are run together using the same project specifications, allowing a direct comparison of results.

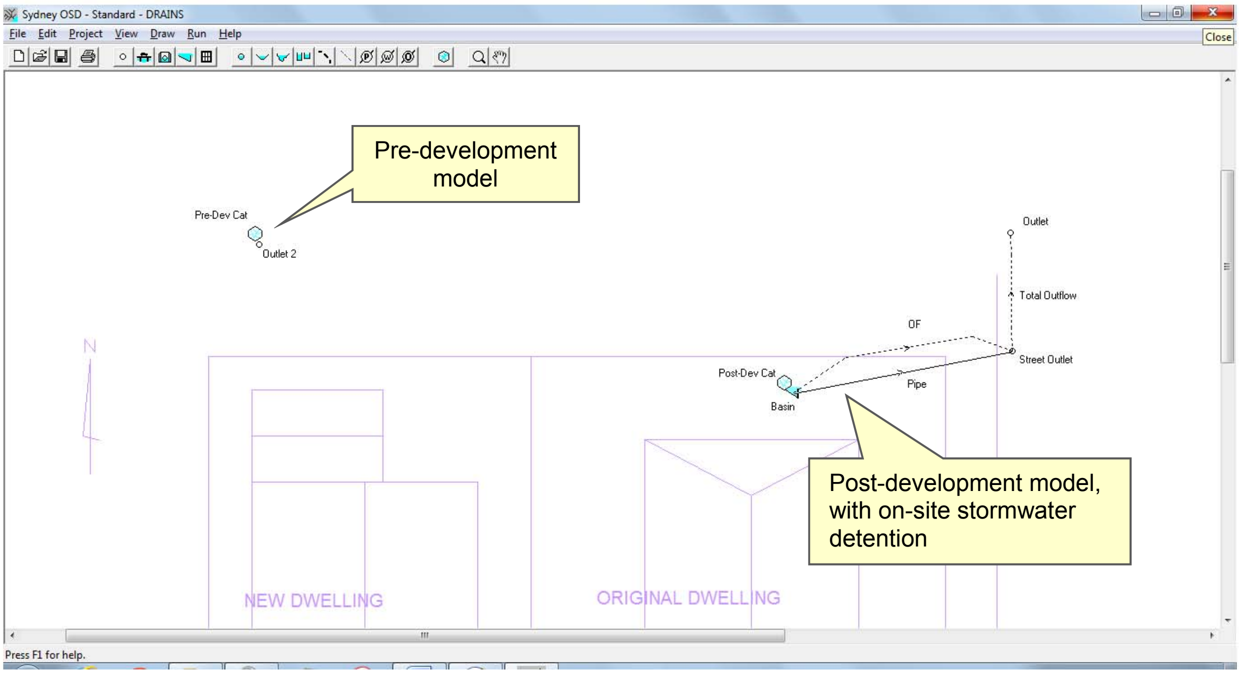


Figure 2.58 Two Drainage Systems Set Up in *DRAINS* for Comparison

2.4 Data Bases

2.4.1 General

By storing data about inputs and common components in five data bases that are easily accessible from drop-down list boxes, *DRAINS* makes it easy to select and alter hydrological models, rainfall patterns, pipe types, pit types and overflow route cross-sections. By referring to standardised types, the amount of data that has to be entered into files is greatly reduced.

The role of data bases is particularly important in the *DRAINS* pipe design procedure. Pipes and pits are both organised into types or families of different sizes from which the program can select.

Data bases can be set up, element by element, using the editing procedures described in the following sections. Hydrological model and rainfall pattern data bases can be stored in template files, and retrieved, as described in the next section. Pipe, pit and overflow route data bases can be imported directly into *DRAINS* using the **Default Data Base** option in the **Project** menu (for a new project) and the **Import ► DRAINS Database (DB1) File…** in the **File** menu (for existing *DRAINS* files).

2.4.2 Standardised Data Bases

When you start *DRAINS* it loads the standardised data base file, **`Drains.db1`**, located on the **`C:\ProgramData\Drains`** folder. This contains information on pipe, pit and overflow route components that are likely to be used in your model..

If you work in only one geographical area, always with the same hydrological model and set of storms, this file need not change. In this case, when you first use *DRAINS* you should set up the storms and hydrological model for your area, set up the pipe, pit and overflow route data bases, then save the file as a template or base that can be used whenever you begin a new project in the area. This file should not

contain pipes or other components. If you work in different locations, you will need to set up a different template file for each geographical area.

Another way to set up a file with required data bases is to open a *DRAINS* file with the data bases that are required, and then close this. The drainage system disappears, hydrological model and data bases remain. The data for pits, pipes and overflow routes can be changed using the **Project → Default Data Base** option, and editing the entries. You can then copy this file as a template file and start a new job with a different filename.

2.4.3 Hydrological Models

The set ups for ILSAX, the rational method and storage routing hydrological models are described in Chapter 1. *DRAINS* is structured to deal with two categories of hydrological model:

- ILSAX, extended rational method and storage routing models that produce hydrographs, developing a time series of flowrates, and
- rational method models that produce only peak flows,

and to apply different forms of rainfall data (hyetograph patterns and intensity-frequency-duration (I-F-D relationships) with these model types.

It is possible to develop a number of different ILSAX models, say for different soils, and to mix these in a model. The storage routing models can be mixed with ILSAX models, although it is only possible to have one type. You cannot mix RORB and WBNM models, for example. However, it would be possible to create a *DRAINS* model that used three kinds of ILSAX model and two kinds of RORB model. The extended rational method cannot be mixed with any other model. Three different kinds of rational method model can be applied, as shown in Figure 2.59, and you can inter-mix these.

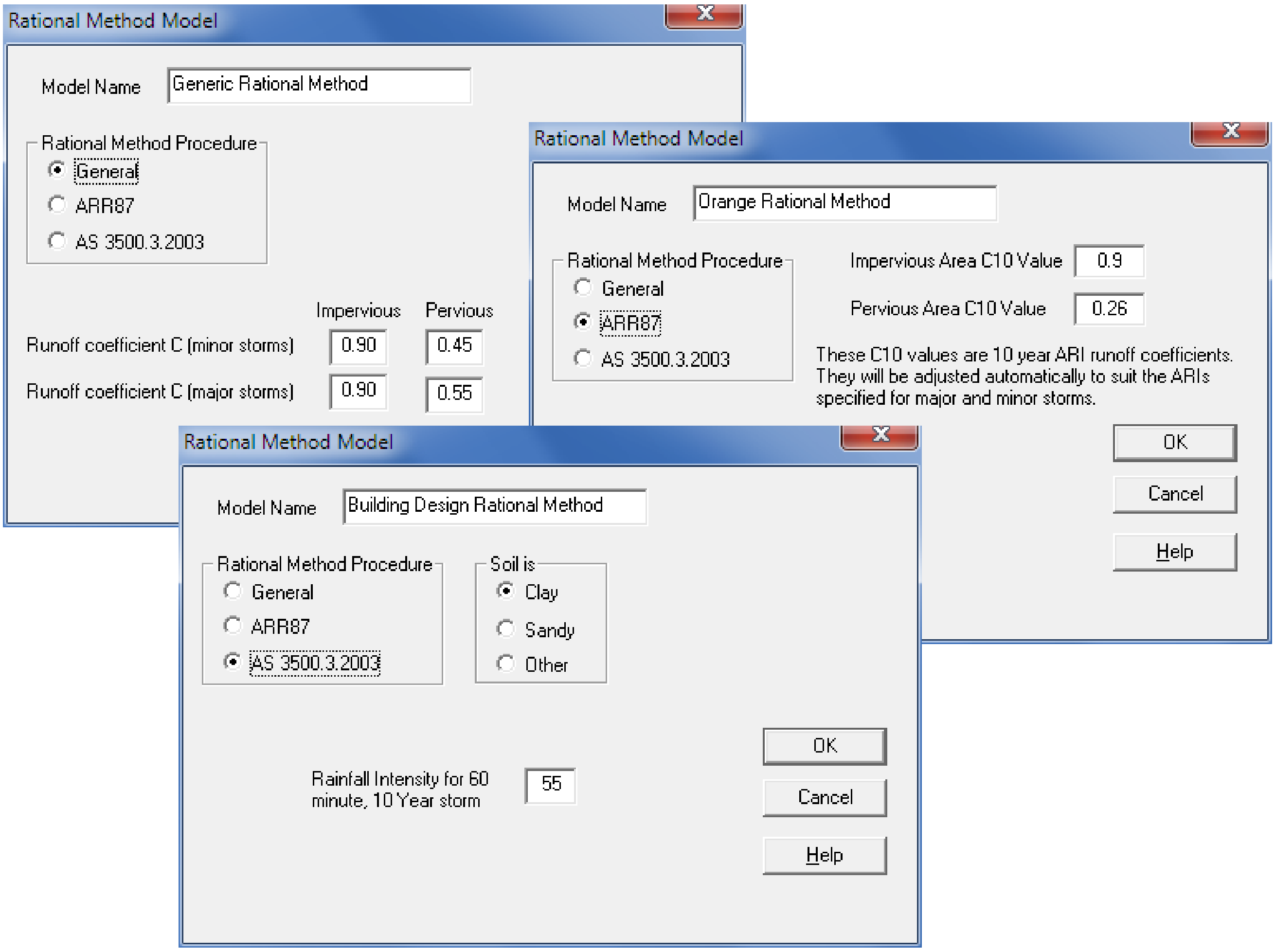


Figure 2.59 Rational Method Selection Property Sheets

Many models of different types can be stored in the Hydrological Model data base. The hydrological model that is selected in the Hydrological Specifications dialog box acts as a default model that applies to

all sub-catchments. However, in many cases a local model can be selected in the property sheet for a particular sub-catchment, as shown in Figure 2.60.

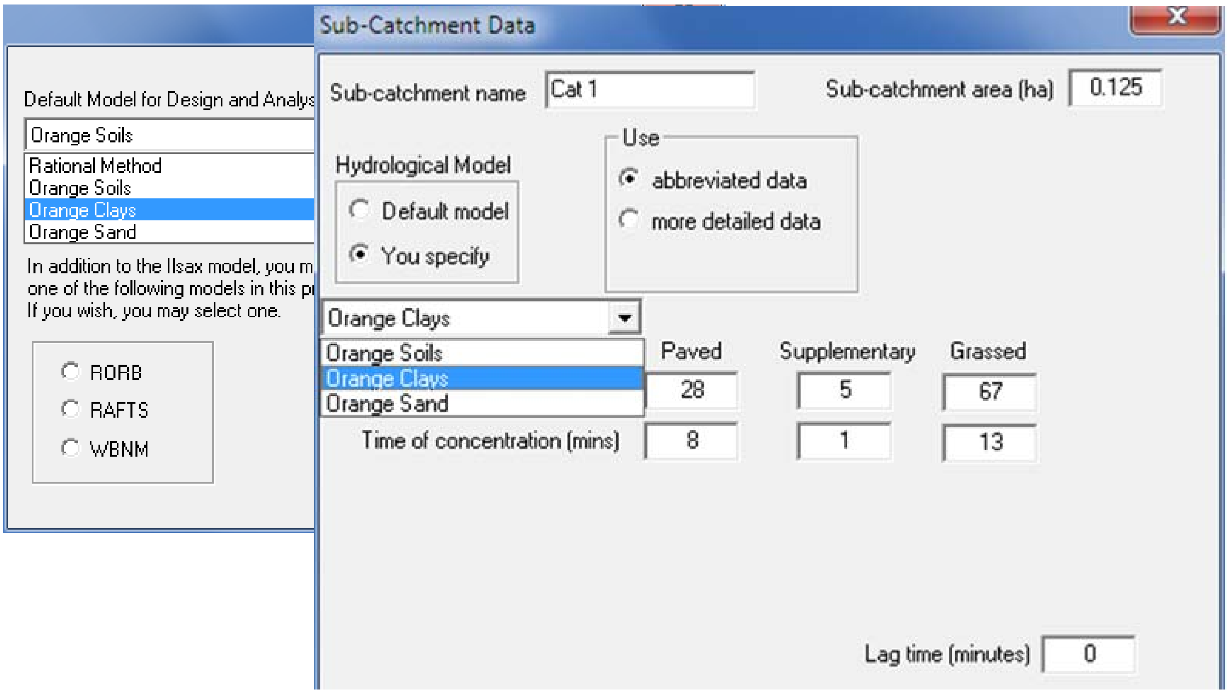


Figure 2.60 Selection of a Default and a Local Hydrological Model

2.4.4 Rainfall Data Bases

(a) New ARR2013 Procedures

At the time of updating this manual, the Commonwealth Bureau of Meteorology and Engineers Australia are in the process of introducing new sets of design rainfall for all of Australia, as set out in http://www.bom.gov.au/water/designRainfalls/ifd/index.shtml, shown below:

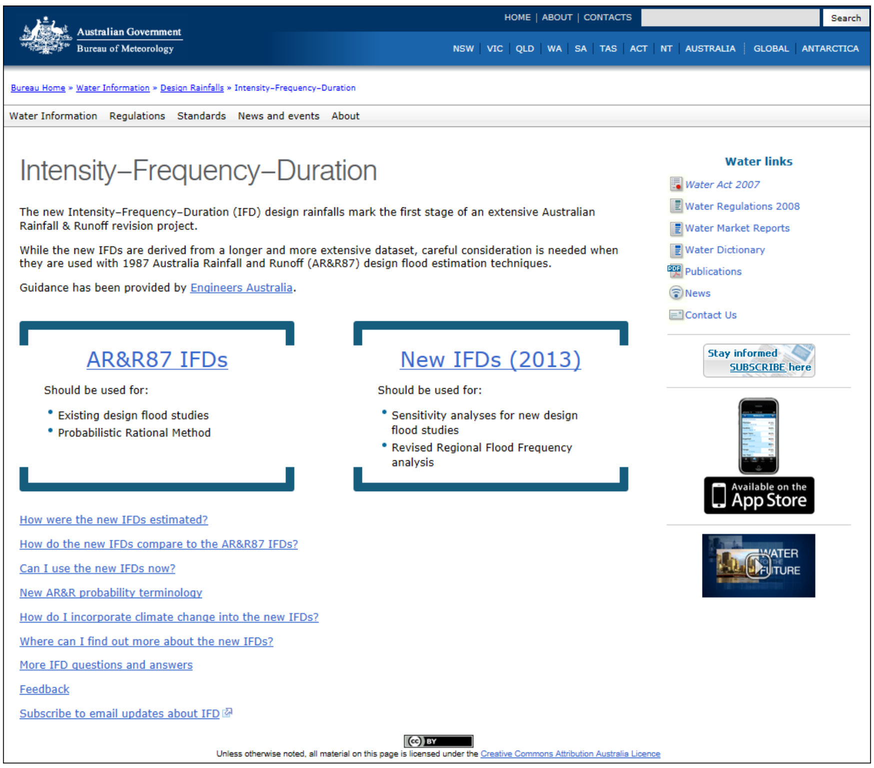


Figure 2.61 Bureau of Meteorology Website

Rather than recommending that the new design rainfall estimates be adopted in preference to the older ones from *Australian Rainfall and Runoff*, 198, the initial advice from these organisations is to use these cautiously, perhaps because these estimates are lower than the 1987 values at many locations.

Other changes are that the new intensity-frequency-duration (I-F-D) values are expressed as depths of rainfall over a number of durations, rather than intensities, and that frequencies are defined as exceedances per year (EY) and annual exceedance probabilities (AEPs) in %, rather than average recurrence intervals (ARIs). It appears that this situation will take some time to sort out, so *DRAINS* retains inputs for older procedures, and will accommodate the new procedures when users require these.

While the Bureau has issued new rainfall intensity or depth information, there is, as yet, no new rainfall temporal patterns to accompany these. New patterns will not be available for two or more years, and it appears that the only choice for designers requiring hyetographs will be to use the new I-F-D data with the old 1987 temporal patterns.

The new design rainfall intensities can be converted to design patterns in *DRAINS* using the Single Entry procedure described in Section 1.2.1(a) in Figure 1.8 to Figure 1.11. The steps required are

i. Define a table of rainfall depths for the design location (specified by latitude and longitude), entering additional Standard Durations as required.

Analysis

Standard Durations

☑ 1 - 30 minutes
☑ 1 - 12 hours
☑ 24 - 168 hours

Non-Standard Durations

Duration: [ ] minutes +

Update Reset

Location

Label: Woop Woop
Latitude: 35 [Nearest grid cell: 34.9875 (S)]
Longitude: 140 [Nearest grid cell: 140.0125 (E)]

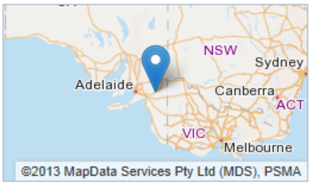


Table Chart

IFD Design Rainfall Depth (mm)

Issued: 29 July 2013

Rainfall depth for Durations, Exceedance per Year (EY), and Annual Exceedance Probabilities (AEP).

	EY	Annual Exceedance Probability (AEP)					
Duration	**1EY**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 min	1.2	1.4	2.1	2.6	3.2	4.0	4.7
2 min	2.0	2.4	3.6	4.5	5.4	6.7	7.7
3 min	2.7	3.2	4.8	6.0	7.2	9.0	10.5
4 min	3.3	3.9	5.8	7.3	8.8	11.1	12.9
5 min	3.8	4.5	6.7	8.4	10.2	12.9	15.0
10 min	5.6	6.6	10.0	12.5	15.3	19.3	22.7
15 min	6.8	8.0	12.1	15.2	18.6	23.5	27.6
30 min	9.0	10.6	16.0	20.1	24.5	30.9	36.3
1 hour	11.5	13.5	20.3	25.4	30.9	38.8	45.4
2 hour	14.2	16.7	25.0	31.3	37.9	47.5	55.5
3 hour	16.1	18.8	28.0	35.0	42.5	53.3	62.4
6 hour	19.7	22.9	34.0	42.4	51.5	65.0	76.4
12 hour	23.9	27.7	40.8	51.0	62.2	78.8	93.0
24 hour	28.6	32.9	48.3	60.3	73.5	93.4	110.5
48 hour	33.4	38.3	55.6	69.2	83.8	105.9	125.0
72 hour	36.1	41.2	59.3	73.3	88.3	110.8	130.4
96 hour	37.9	43.3	61.6	75.5	90.5	113.0	132.7
120 hour	39.4	44.8	63.1	76.7	91.6	114.0	133.7
144 hour	40.7	46.1	64.1	77.3	92.1	114.3	134.1
168 hour	41.8	47.2	64.9	77.5	92.3	114.5	134.4

Figure 2.62 Depth-Frequency-Duration Table

ii. For each duration, divide the depth by the duration in minutes, and multiply by 60 to obtain the required intensity. For example, for a 20% AEP, 30 minute duration, the depth of 16.0 mm corresponds to an intensity of 16.0 / 30 * 60 = 32 mm/h.

Iii This needs to be applied with a 30 minute duration pattern from ARR87, which can be done applying the procedure in Section 1.2.1(a), as shown below:

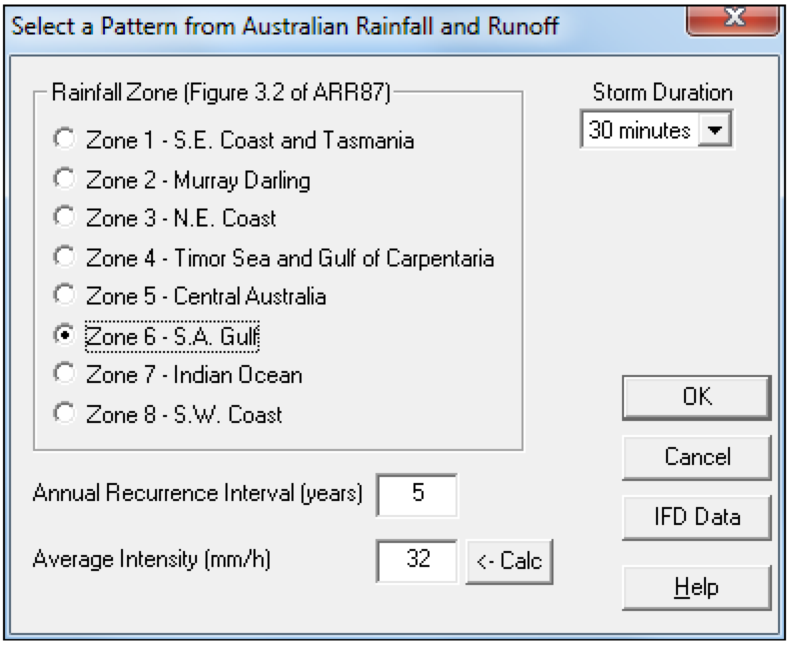


Figure 2.63 Date Entry for 2013 Design Rainfall Pattern

Pressing OK will produce the required pattern. A suitable title for this 2013 interim estimate can be entered.

This procedures needs to be repeated for each design storm pattern required.

(b) Entering Single and Multiple ARR87 Patterns

The setting up of standardised Australian patterns in the Rainfall Patterns dialog box has been demonstrated in Section 1.2.1(a) in Figure 1.8 to Figure 1.11, with patterns being entered one by one . It is also possible to enter multiple patterns in a single operation, using 1987 intensity-frequency-duration (I-F-D) data from the Bureau of Meteorology website, www.bom.gov.au.

Multiple patterns can be entered by downloading data from the Bureau of Meteorology's site http://reg.bom.gov.au/hydro/has/cdirswebx/cdirswebx.shtml shown in Figure 2.64, and pasting it into *DRAINS*.

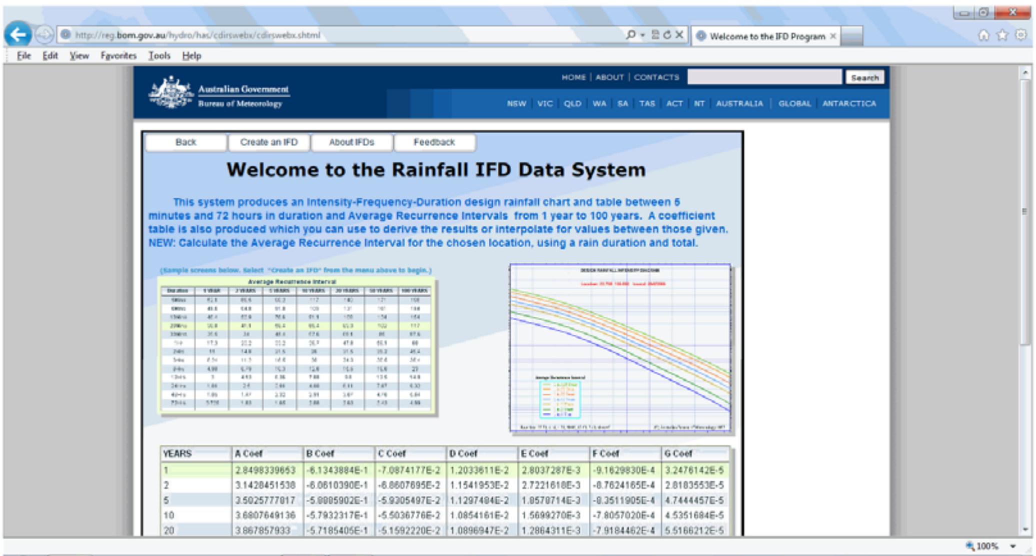


Figure 2.64 Bureau of Meteorology Web-Page

To apply the process in *DRAINS*, click the **Add multiple ARR87 storms** button in the Rainfall Data property sheet, which will open the dialog box shown in Figure 2.65

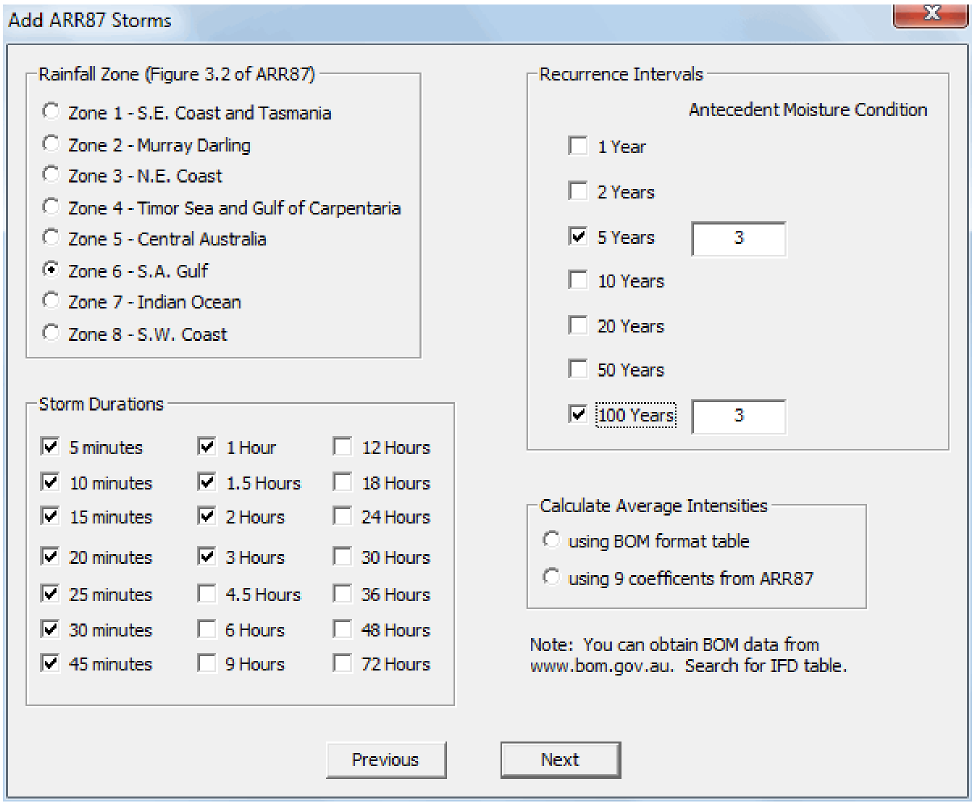


Figure 2.65 Add Multiple Storms Dialog Box

The Zone of Australia, ARIs and durations required can be entered, as shown above. Note that different antecedent moisture conditions (AMCs) can be provided for ILSAX models. When the option of **using BOM format table** selected and the **Next** button is clicked, this will open the following dialog box:

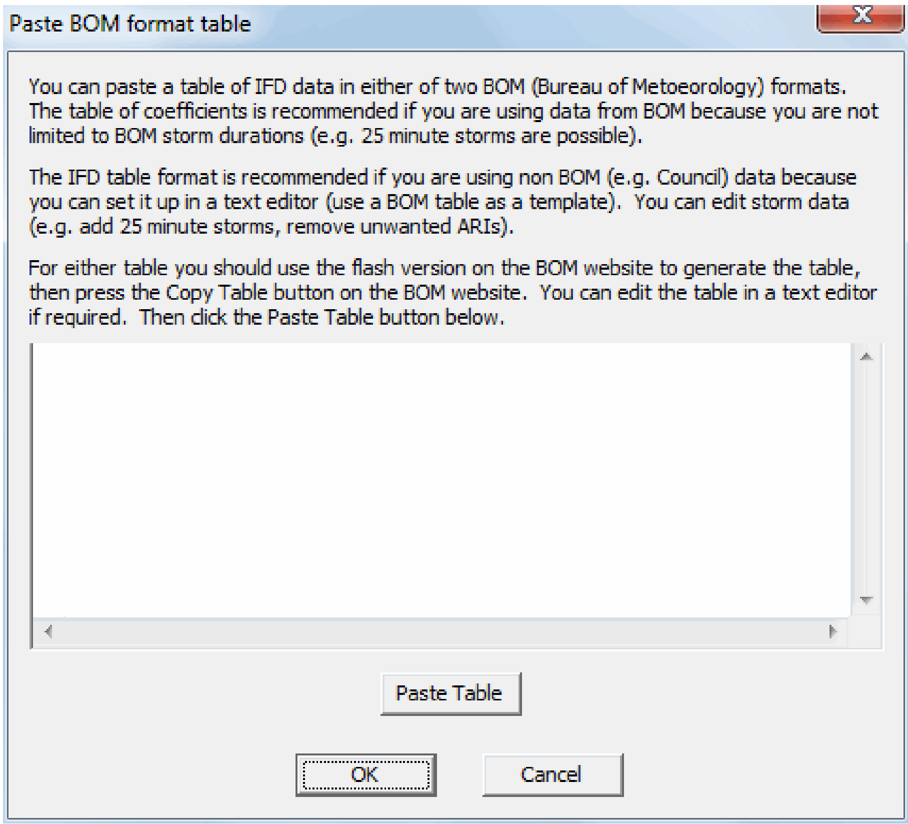


Figure 2.66 Paste BOM Format Table Dialog Box

Now go to the 'flash' BOM page, and press the **Create an IFD** button. The dialog box shown below will open.

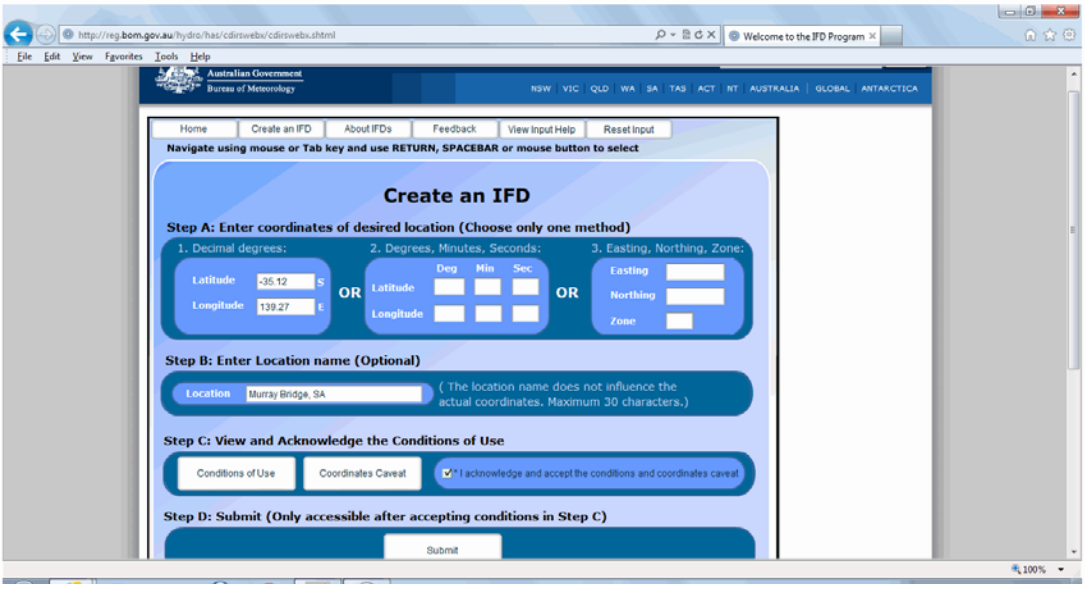


Figure 2.67 Create an IFD Dialog Box

Enter the latitude, longitude and name of the site, click the **Conditions of Use** box, and press the **Submit** button to produce the following web page:

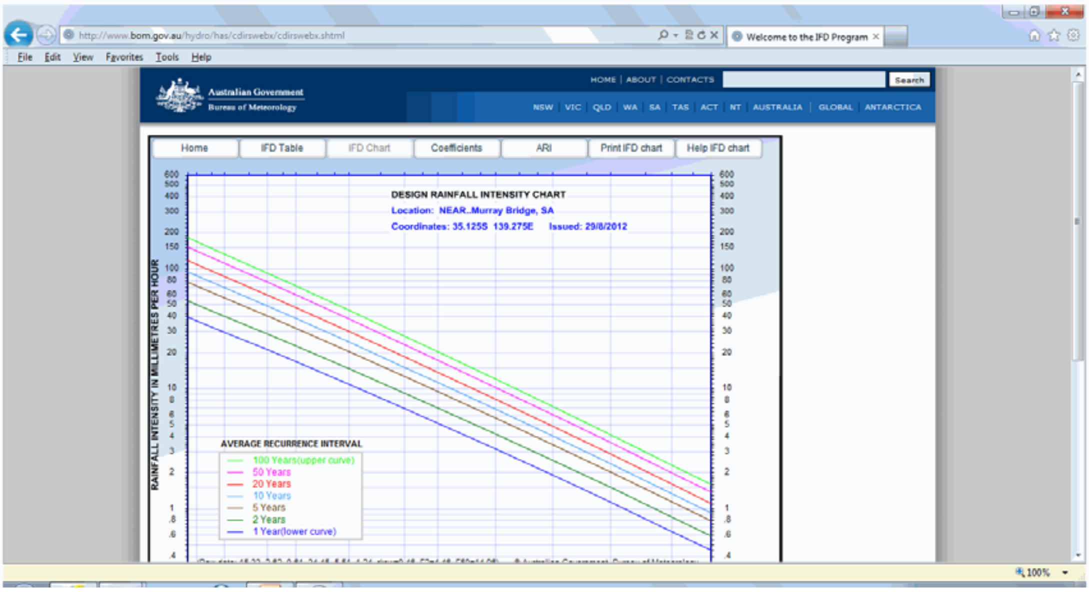


Figure 2.68 Output from CDIRS Procedure

Next, click the **Coefficients** button to open Figure 2.69. Click the **Copy Table** button, and then go back to *DRAINS*, to the **Paste BOM format table** dialog box, and click the **Paste Table** button, which displays Figure 2.70

The text shown is a set of polynomial coefficients in csv (comma separated variable) format. When the OK button is clicked, the desired storms are added to the rainfall pattern database, as shown in Figure 2.71 . As an alternative, you can select **IFD Table** rather than **Coefficients** in the BOM output that shows the IFD curves, and go through a similar process.

(c) Entering Synthetic Storms for the Extended Rational Method

As an alternative to working with design storm patterns from *Australian Rainfall and Runoff* 1987, the Extended Rational Method can be applied using synthetic patterns derived from the local intensity-frequency-duration (I-F-D) relationships.

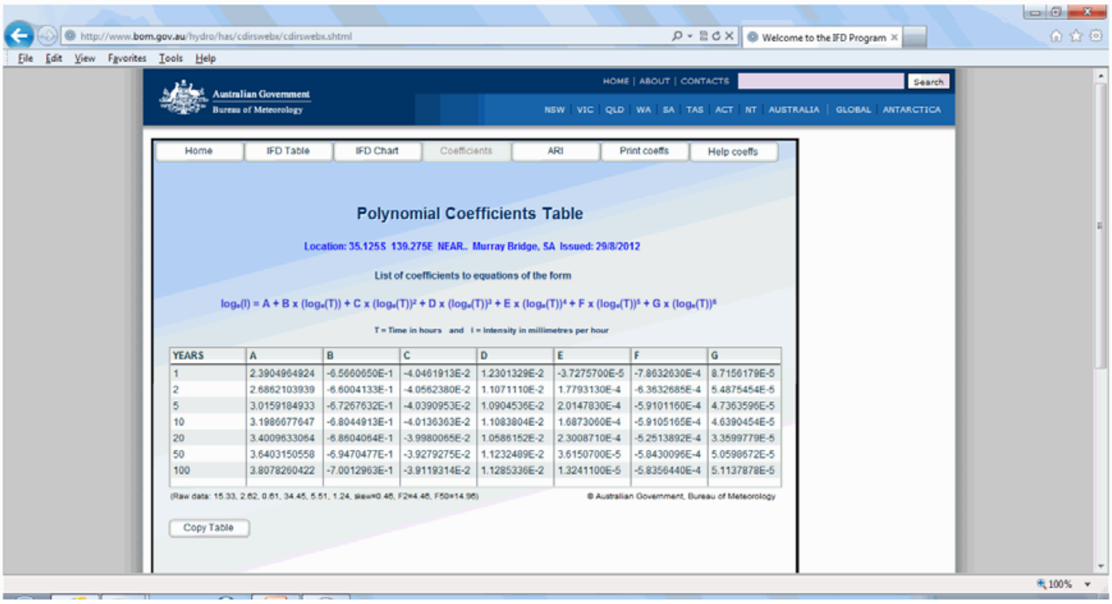


Figure 2.69 I-F-D Coefficients

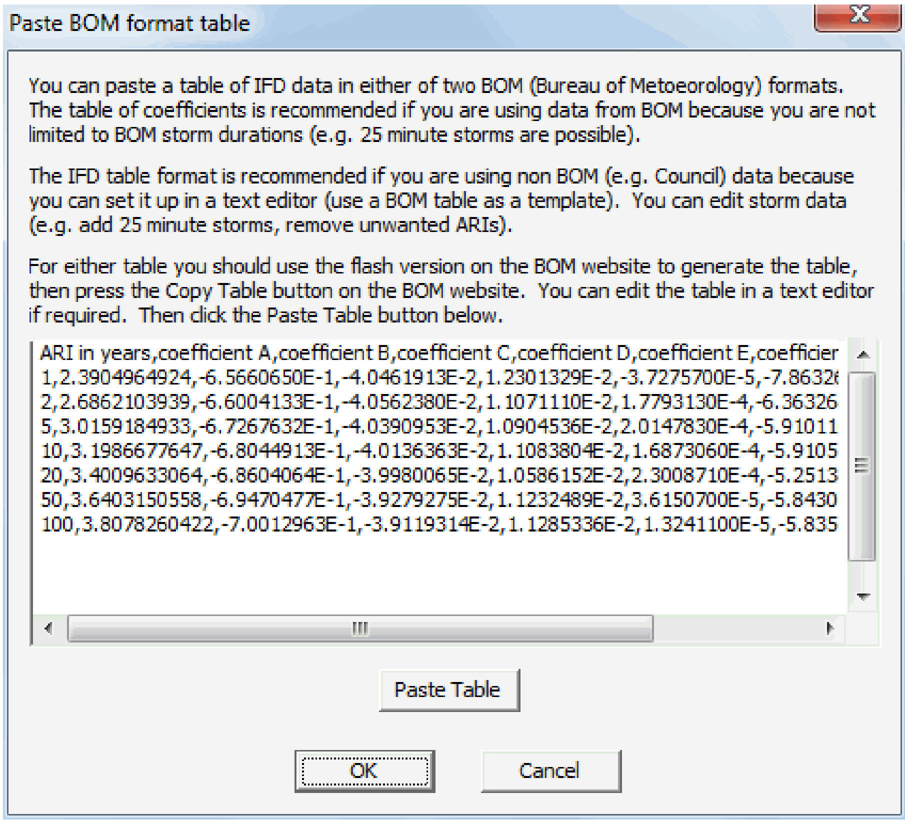


Figure 2.70 Paste BOM Dialog Box with Coefficients Displayed

The latter will give the same peak rainfall values as the rational method because they are derived directly from the I-F-D data. They can be added to the rainfall pattern data base by pressing the **Add Synthetic Storm** button in the Rainfall Data property sheet and completing the dialog box shown in Figure 2.72 to produce the pattern shown in Figure 2.73.

The four intensities must be obtained from the local I-F-D data. A block duration of 1 minute is recommended to allow exact matching of 5, 6, 7, 8, etc. minute intensities in the I-F-D data. The volume of the hydrograph will increase for longer storm durations. The storm duration selected should be considerably longer than the time of concentration of the catchment.

The **2/3 - 1/3** option pushes the peak of the rainfall pattern to the right so that its peak occurs at two-thirds of the specified storm duration. Further information on this can be obtained in the San Diego County Hydrological Manual available on the internet. This is claimed to be more conservative for detention basin design.

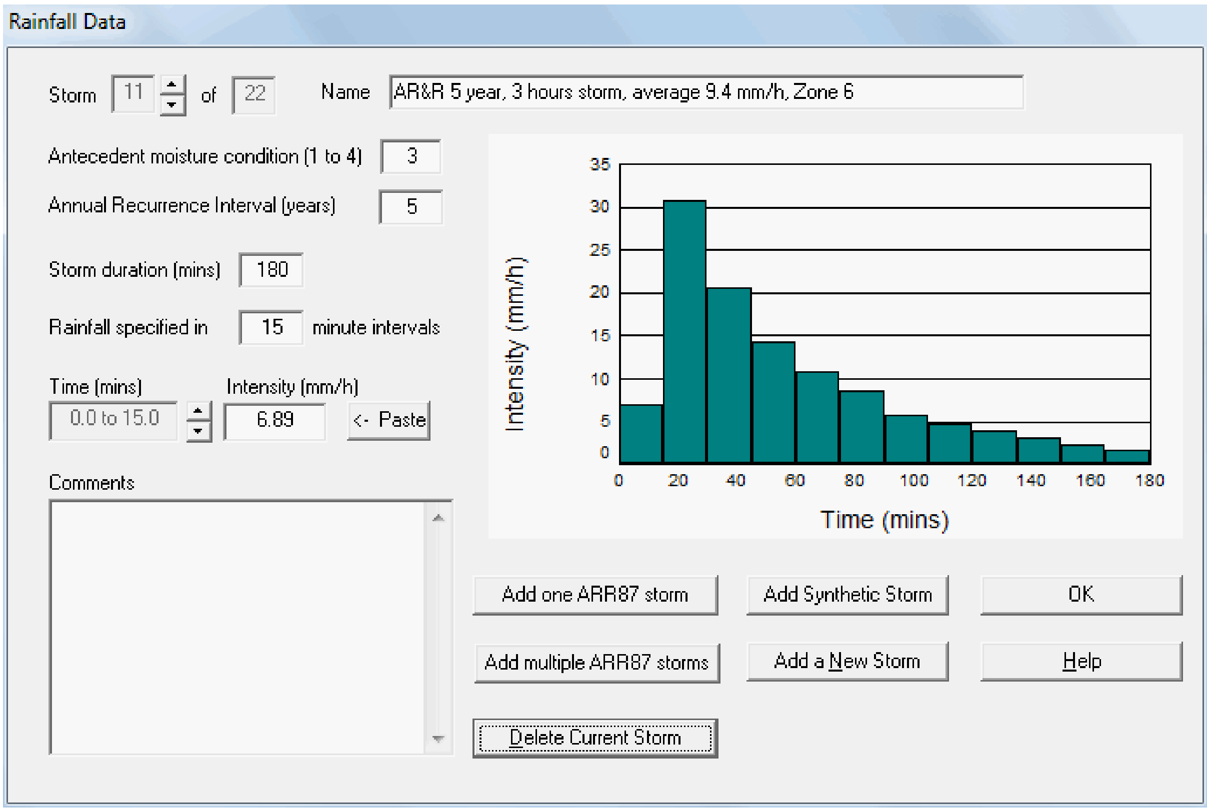


Figure 2.71 Added Multiple Storms

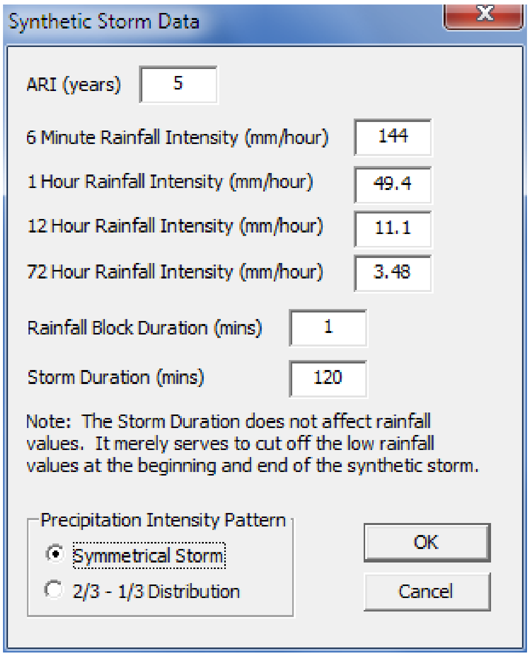


Figure 2.72 Dialog Box for Setting Up Synthetic Storms

Synthetic storm patterns consist of a number of nested storms, with the average intensity for any duration equalling the intensity specified by the I-F-D relationship for that duration. Originally known as the Chicago storm patterns, these relationships have been used in the United States for some time and are also applied in the UK and Hong Kong.

(d) Adding Storms by Hand or by Spreadsheet Transfer

It is also possible to set up non-standard patterns by clicking the **Add a New Storm** button in the Rainfall Data property sheet to open the box shown in Figure 2.74.

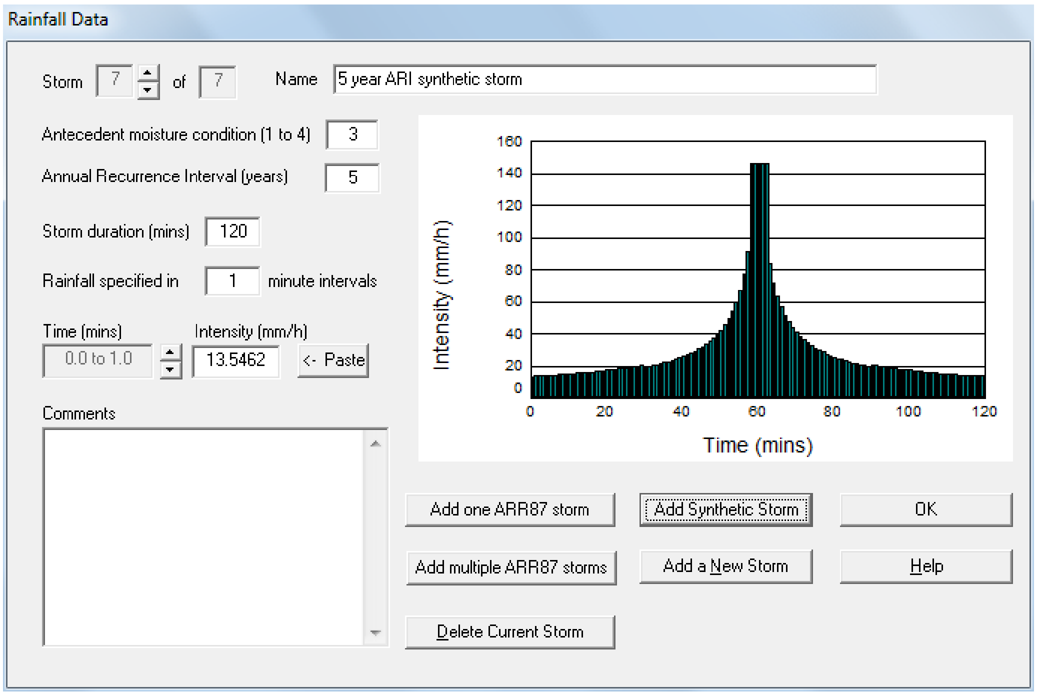


Figure 2.73 Synthetic Rainfall Pattern

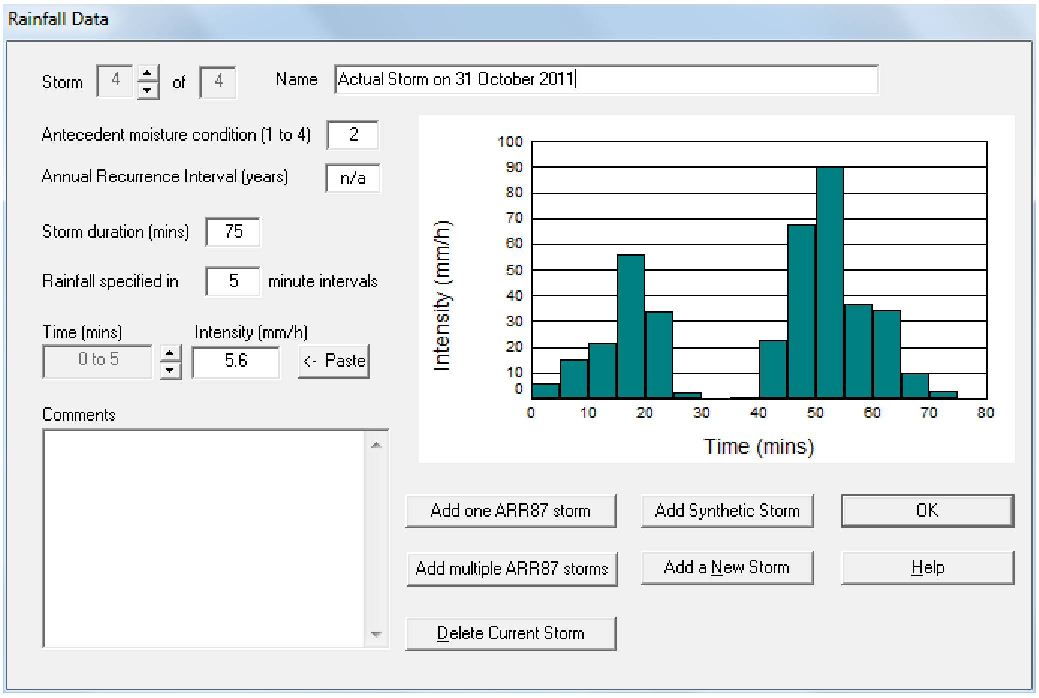


Figure 2.74 Manual Data Entry of a Rainfall Hyetograph

0	5.6
5	14.9
10	21.3
15	55.6
20	34
25	2.3
30	0
35	0.5
40	22.9
45	67.7
50	90.4
55	36.4
60	34.2
65	10
70	3

The duration of the pattern and the time step can be set, and the rainfall intensities entered directly in the text box labelled 'Intensity (mm/h)'. Corrections can be made by locating a value using the spin box for the intensities, and altering the contents of the text box.

An average recurrence interval is required to specify factors used to determine runoff coefficients in the Extended Rational Method. It is possible to enter values between 0.1 and 999 years. If actual storms are being modelled, a rough estimate of the ARI should be entered. If probable maximum precipitation storms are to be modelled, a value of 999 might be used.

It is also possible to enter data from a spreadsheet by setting up two spreadsheet columns as shown to the right. The left one should contain the times in minutes of the start of each block, beginning with zero. The time divisions used must be the same throughout; they cannot be varied. The right column should contain the

rainfall intensities corresponding to the given times in mm/h. This facility allows complex patterns such as that shown in Figure 2.75 to be entered.

You should copy both columns to the Windows Clipboard and then transfer from the spreadsheet program to *DRAINS*. Clicking on the **<- Paste** button in the property sheet in Figure 2.74 will automatically enter the rainfall pattern. This is an effective way of entering patterns for probable maximum precipitation and extreme flood modelling.

At times *DRAINS* may not calculate hydrographs for as long a period as you may require. The calculation period can be easily extended by increasing the given storm duration in Figure 2.74. This automatically assumes that the extra rainfall ordinates are zero, and extends the calculation period.

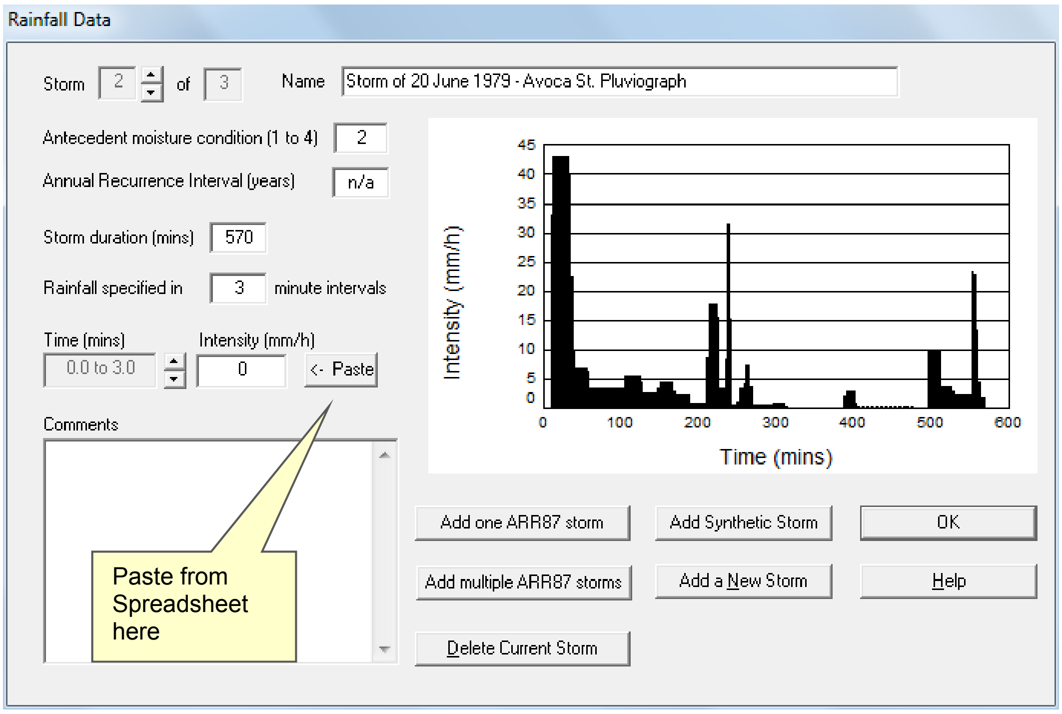


Figure 2.75 Observed Actual Rainfall Pattern (from file `Ilsax10.drn`)

Whatever data are entered into the rainfall database, they must be nominated as major or minor storms using the options shown in Figure 1.11, in order to run with the available options (as set out in Section 3.4). There is the only way that rainfall date can be applied in runs. There is no way of storing a specific set of rainfall patterns outside of the major-minor setup.

2.4.5 Pipe Data Base

The Pipe Data Base property sheet shown in Figure 2.76 is opened by selecting the **Pipe Data Base …** option in the **Project** menu. This operates in two stages. The first is to define a pipe type, and to specify its name, whether it is circular or rectangular, its roughness (according to the pipe friction formula set in the **Options** property sheet called from the **Project** menu), and its minimum cover (m). The second stage is to provide data for specific pipe sizes in the property sheet shown to the right in Figure 2.76. For circular pipes, the nominal diameter, internal diameter (I.D.) and wall thickness must be supplied in mm. For rectangular pipes, the width (m), height (m) and wall thickness (mm) must be supplied.

The check box labelled '**Not available for selection in design runs**' allows you to omit pipe sizes that are considered too small or are unavailable. If you wish to vary cover depths with pipe sizes, or to have different classes of pipes (with different wall thicknesses), specific pipes classes should be entered as pipe types.

Once established, the data base is easy to apply. Pipe types and sizes are readily accessed from the Pipe Data property sheet. The data base can be edited, and factors such as cover depths can be altered. When such changes are made, the title should also be changed to note that the default set of pipe data has been altered. Additional pipe types can be added using **Import ► DRAINS Database (DB1) File…** in the **File** menu, which requests the name of a **.db1** file to be added. These are usually located in the **`C:\Program Files\Drains\Program`** folder. When a file is nominated, *DRAINS* opens the dialog box shown in Figure 2.77. You can then select the particular data you wish to transfer.

Note that deletion of pipe types and sizes is not possible if pipes are present in the Main Window. It can be done on a template file that does not contain any drainage system components.

When a *DRAINS* file is opened and closed, its pipe, pit, overflow profile data bases remain in DRAINS, and some may be inherited by the new system. Template files can also supply suitable data bases.

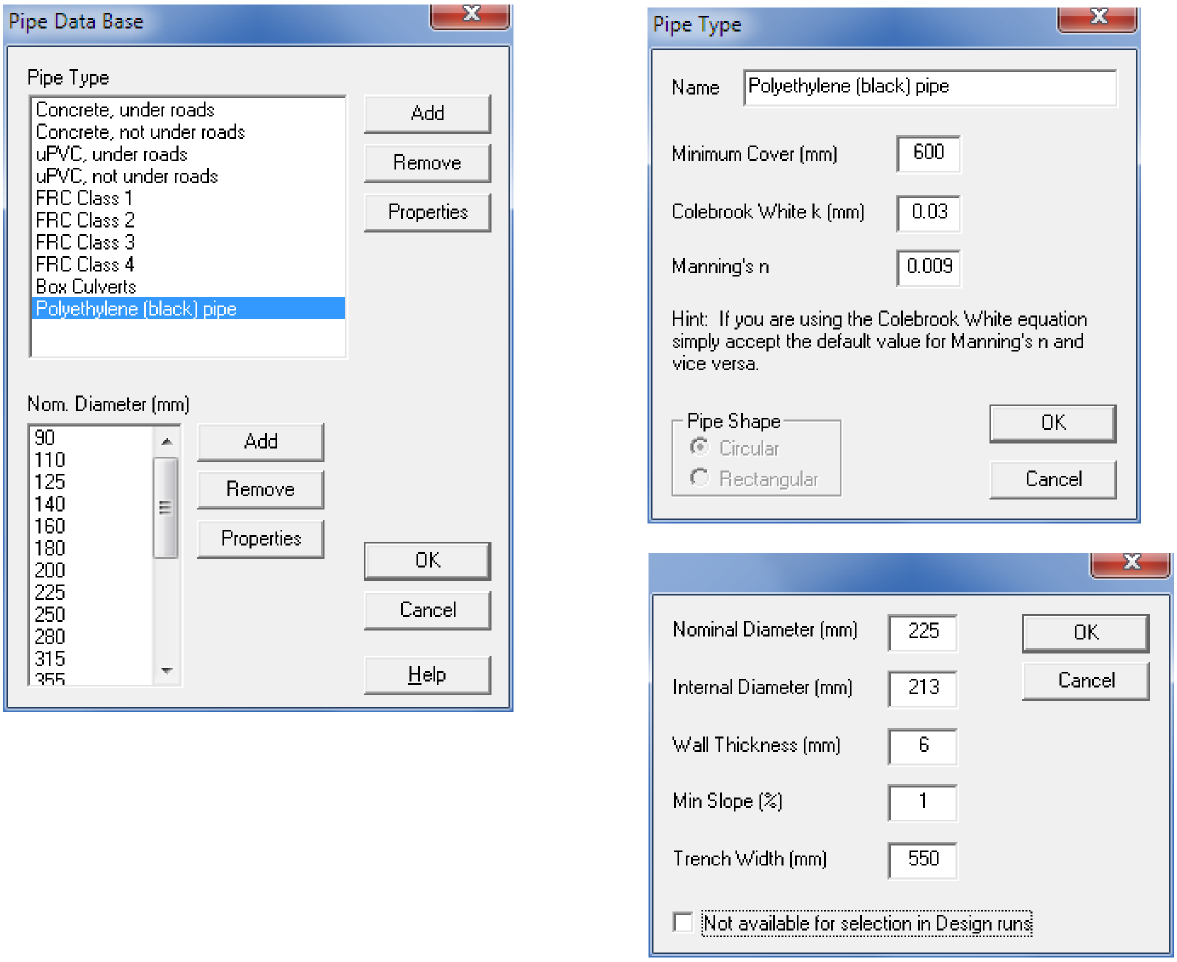


Figure 2.76 Main Pipe Data Base and Pipe Type Property Sheets

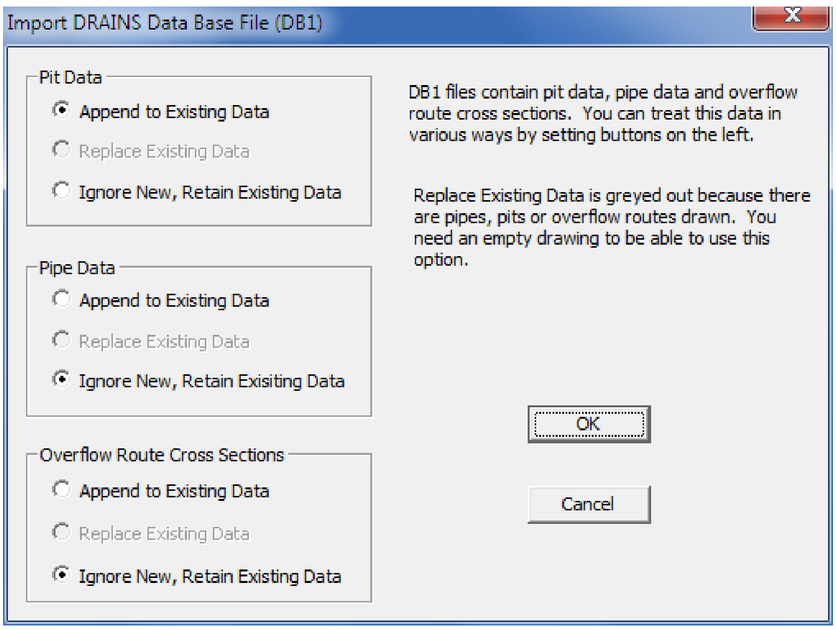


Figure 2.77 Dialog Box for Importation of Additional Pipe, Pit and Overflow Data

2.4.6 Pit Data Base

The Pit Data Base is accessed through the **Pit Data Base**… option in the **Project** menu. As shown in Figure 2.78, pits are organised into types or families of different sizes, in a similar way to pipes. The pit type is described in the Pit Type property sheet, also shown in Figure 2.78.

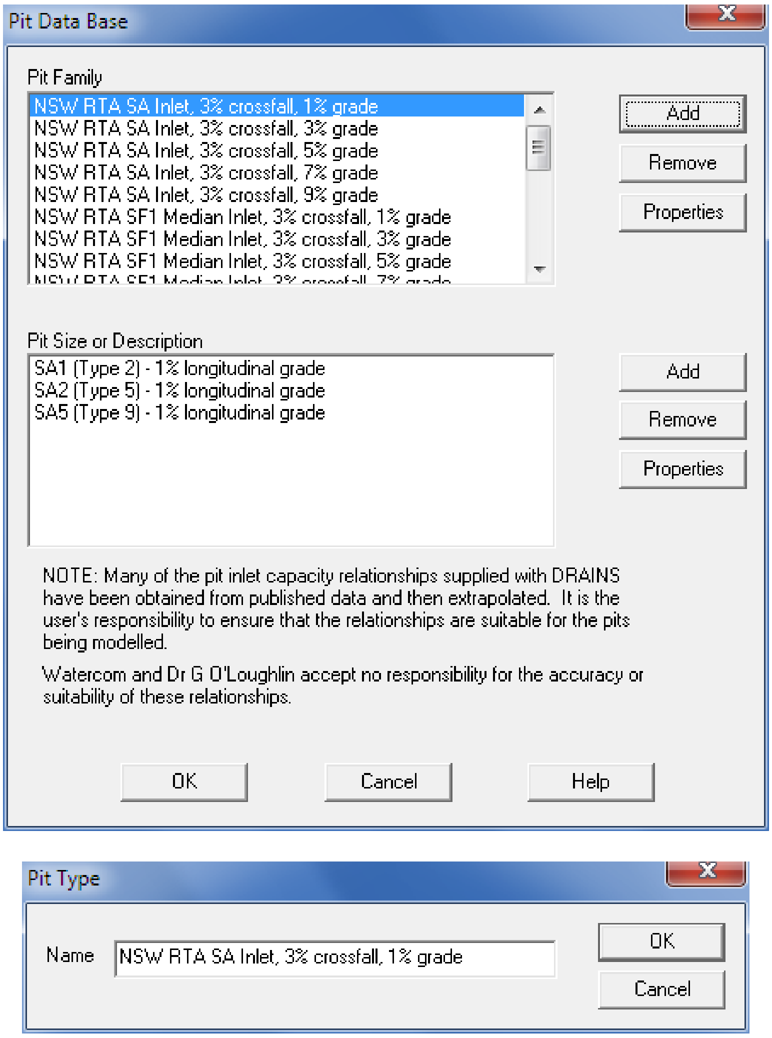


Figure 2.78 Main Pit Data Base Property Sheet and Pit Type Property Sheet

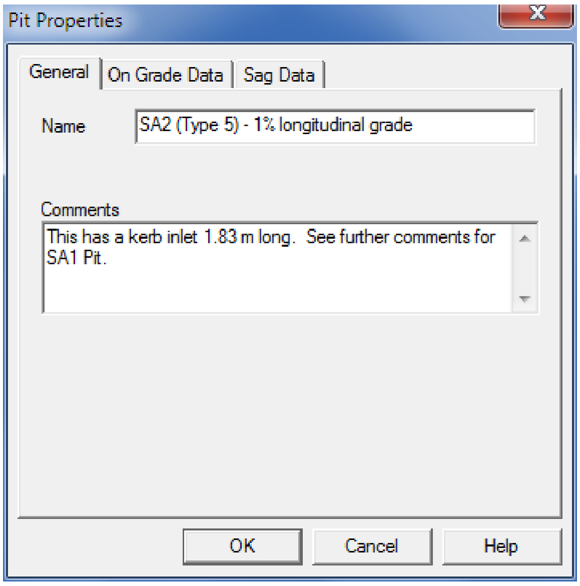
Data for each individual pit is entered in the triple property sheet shown in Figure 2.79. The relationships are entered directly, as tables. This provides flexible relationships, particularly at the top end of the curves. It is possible to set an upper limit on inlet capacities if required.

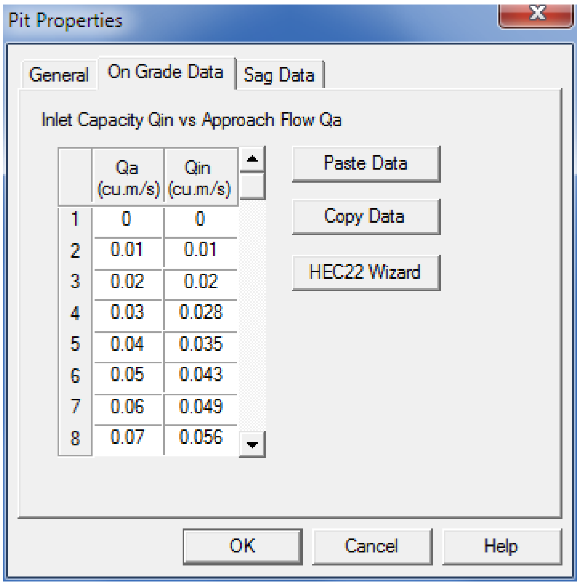
As part of the *DRAINS* design method, sets of relationships for pits in various regions have been provided in **.db1** data files contained in the **`C:/Program Files/Drains/Program`** or **`C:/Program Files (x86)/Drains/Program`** folder, under names such as **`NSW Pits June 2008.db1`**. Relationships for NSW, Queensland, Victoria, the Australian Capital Territory, South Australia and Western Australia are now available. Instead of a single data base, these are made up of sets of relationships that can be combined as required, using the **Import ► DRAINS Database (DB1) File…** option in the **File** menu. Via the dialog box shown in Figure 2.77, additional pit types can be entered into the data base.

This process can be assisted by the **Paste Data** and **Copy Data** buttons in the On-Grade Data and Sag Data windows shown in Figure 2.79. The first function can bring in data from two columns of a spreadsheet, in the same way as for rainfall patterns (Section 2.4.4). The **Copy Data** function can transfer data to a spreadsheet, or directly to another *DRAINS* pit data base. A pit data base can be selected for a new project using the **Default Data Base** option in the **Project** menu, in the dialog box shown in Figure 2.80.

Through Watercom Pty Ltd, inlet capacity relationships are available for many Australian pit types, as indicated in Table 5.13 to Table 5.19.

These may be periodically updated. To update a *DRAINS* model it will be necessary to import the data in the revised **.db1** file using the **Import ► DRAINS Database (DB1) File…** option in the **File** menu, and then change the name of the old relationship to show that it is obsolete. The pit types nominated for particular pits can then be changed one by one, or altered by exporting the system data to a spreadsheet, as described in Section 3.5.4, altering pit type and size names in the columns, and then exporting the altered spreadsheet back to the *DRAINS* model.





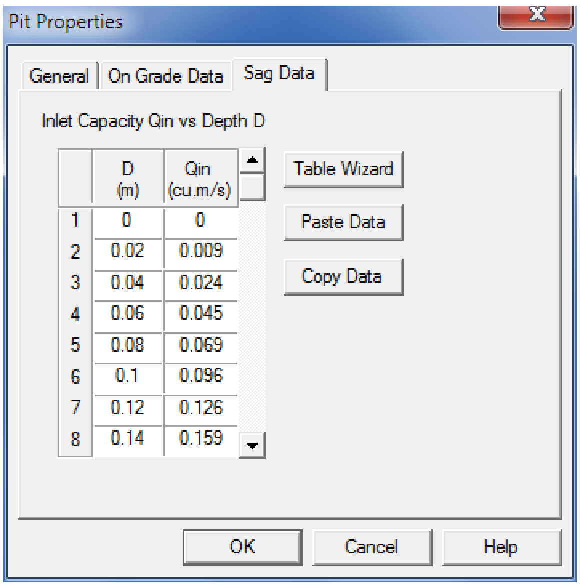


Figure 2.79 Inlet Capacity Data for an Individual Pit

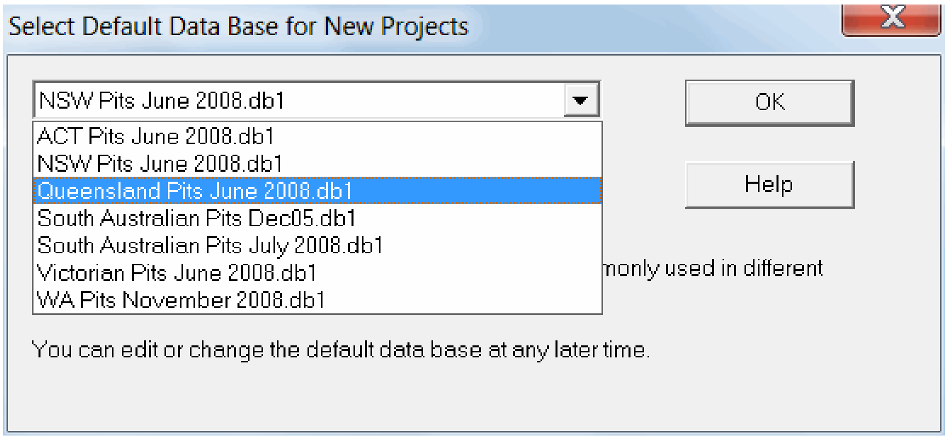
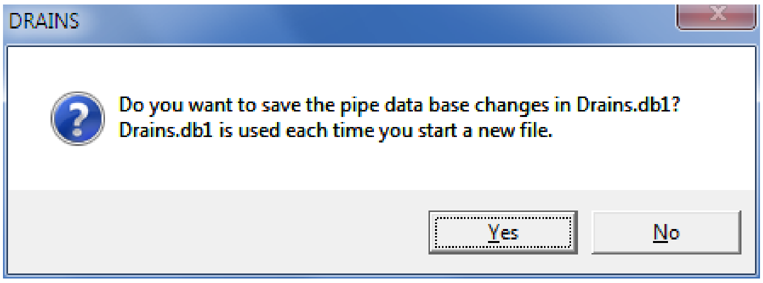


Figure 2.80 Dialog Box for Selecting a Default Data Base

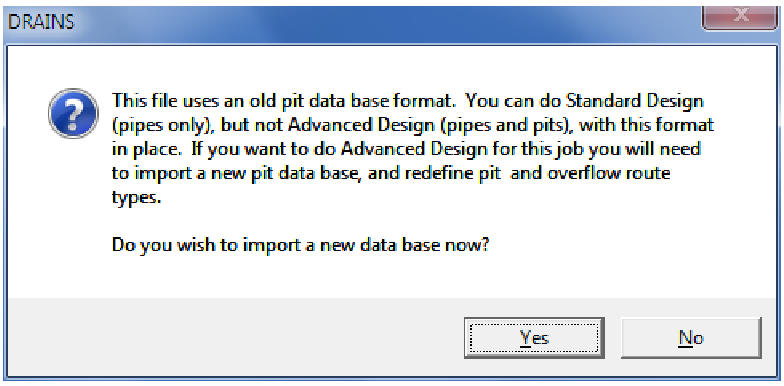
However, there are many types of pit for which no relationships are available. Using the HEC22 procedures in the wizards for on-grade and sag pits implemented by the buttons shown in Figure 2.79, inlet capacity relationships can be estimated for these.   A 'generic' pit spreadsheet that calculates capacities using methods from the US Federal Highway Administration HEC-22 manual (US FHWA, 2001) can also be applied. More explanation is provided in Section 5.5.3.

If a Pit Data Base is opened, and a change is made to the data for one of the pits, the following message appears when this is closed by clicking on the **OK** button: Clicking the **Yes** button sets up the file's pit data base as the selected one.



Various regional pit types are available as **`.db1`** files in the **`C:/Program Files/Drains/ Program`** folder. If **`ACT Pits June 2008.db1`** or **`Queensland Pits June 2008.db1`** is copied as **`Drains.db1`** into the folder **`C:/ProgramData/Drains`**, the ACT or Queensland pit types will be installed. *DRAINS* uses separate folders in **`C:/Program Files`** and **`C:/ProgramData`** because of Microsoft Vista rules for handling files for applications.

DRAINS still accepts old files that use the ILSAX equations described in Section 5.5.1 for pit inlet capacities. However, if you attempt to run the Design method, the following message will appear. It would then be possible to import a new Pit Data Base and to alter each pit's type to conform to this.



2.4.7 Overflow Route Data Base

The property sheet opened from the **Overflow Route Data Base…** in the **Project** menu is shown in Figure 2.81. Using X-Y coordinates, a cross section can be defined for a roadway, footpath or other route that may operate as a path for overflows.

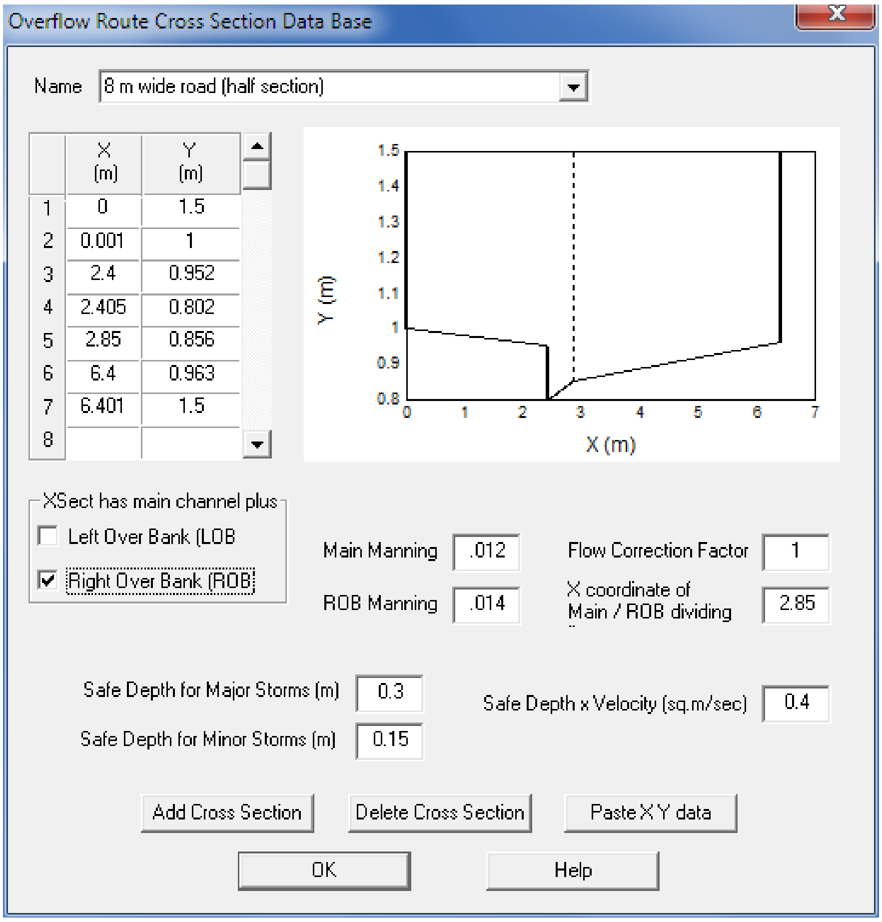


Figure 2.81 Overflow Route Cross Section Data Base Property Sheet

At present, the section may be divided into two zones with different Manning's n roughnesses, by specifying these, and the X value of the dividing line. As X-Y values are entered, the picture shows the section being produced.

In the boxes at the bottom, you can specify safe depths for minor and major storms and a safe depth-velocity product. These are applied at selected cross-sections in the Design method. *DRAINS* works backwards to ensure that overflows from pits are kept to levels that will meet these safety criteria. It does this by providing pits and pipes with the appropriate capacities to do this, following procedures within the *Queensland Urban Drainage Manual* (Neville Jones & Associates et al., 1992).

3. OPTIONS WITHIN *DRAINS*

3.1 Introduction

Most of the functions or processes within *DRAINS* are presented here, referring to the example files that accompany this manual. They are arranged into:

- Input Options,
- Display Options,
- Run Options,
- Output Options, and
- Help Options.

3.2 Input Options

3.2.1 General

The example file in Chapter 1 was established using the screen tools provided on the Toolbar, and their associated property sheets. Other options are available that allow a substantial part of the information required to be inputted by other means. These are mainly implemented through the **File** menu shown in Figure 3.1, and the two additional menus that are opened using the **Import ► and Export ►** options. (Note that not all options may appear when the hydrological model in DRAINS is set to be a rational method model.)

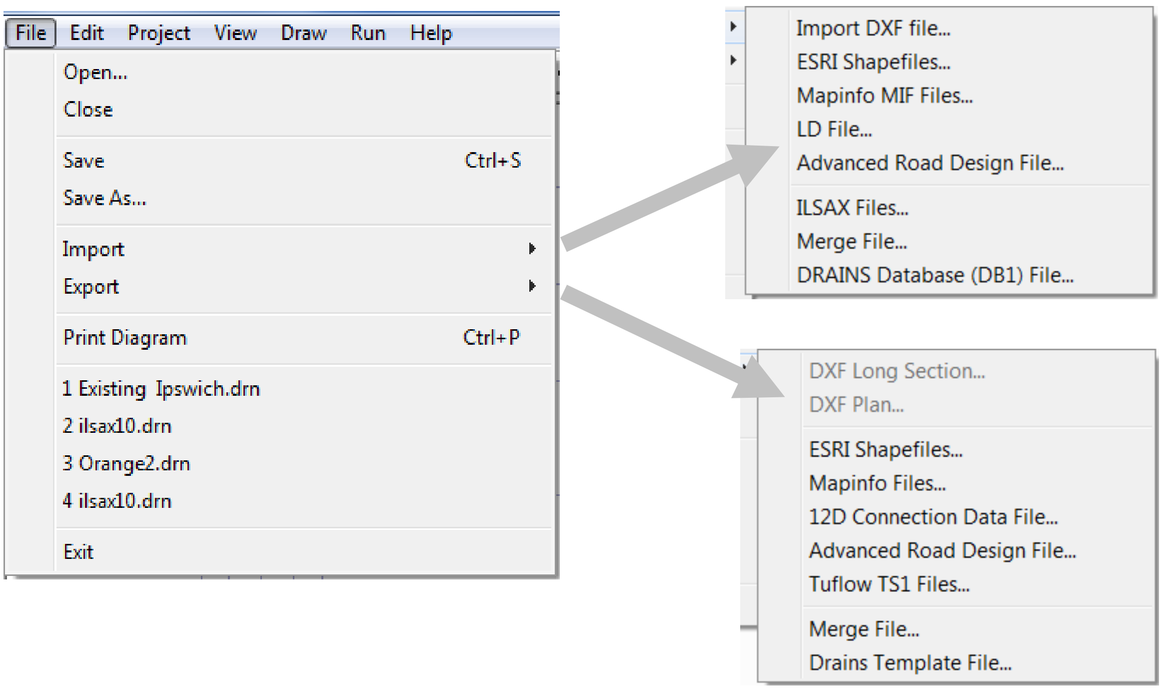


Figure 3.1 The File Menu and Sub-Menus showing Import and Export Options

In design work, it is likely that considerable data will be available from CAD files created by surveyors and used by designers to set out street layouts, cadastral (land boundary) data and positions of services. Some of this data can be taken directly into *DRAINS* by importing CAD files in DXF format. This includes a background showing streets, lot boundaries and other information. Other data obtainable from CAD drawing files, such as sub-catchment areas, will have to be entered into property sheets, or via a spreadsheet.

For investigation of established drainage systems, data is likely to be available in a number of forms: paper plans, CAD drawings, spreadsheet tables, data bases from GIS systems and aerial photographs. *DRAINS* can accept ESRI (ArcView, ArcInfo, and ArcMap) files and MapInfo files. A background can be imported as a DXF file, and spreadsheets can be assembled into a form accepted by *DRAINS*.

3.2.2 Importing DXF Files

(a) New Systems

Where a drainage system has been drawn in a drawing package or digital terrain model, it can be imported into *DRAINS* in DXF format. This is one of the oldest drawing formats, which can be created in almost all technical graphics packages. Newer formats such as DWG, the widely-used AutoCAD binary format, can be converted to DXF format before transfer to *DRAINS*.

The external software package must include three layers:

- one for pits, with the location of each pit marked by a circle,
- one for pipes, with pipes shown as lines, and
- a background, which may show street boundaries, cadastral information and contours.

Other layers can also be present, but will not be used. Lines, poly-lines and arcs on the background layer will be imported into *DRAINS* as a bitmap.

Figure 3.2 shows a drawing created in AutoCAD LT, representing a drainage system assumed to be at Brisbane.

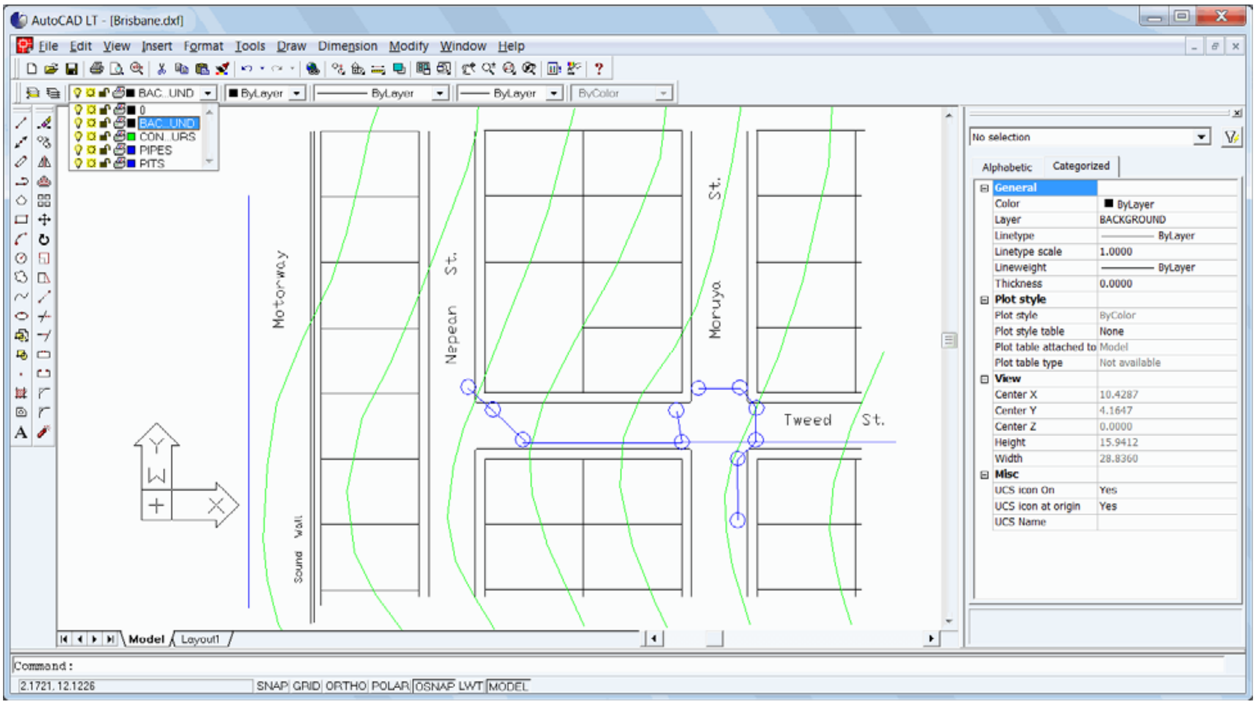


Figure 3.2 Drawing of Drainage Network

Information that is in this file can be imported by opening *DRAINS* and selecting Import a **DXF File…** from the **File** menu. You will be requested to nominate a file with a **.dxf** suffix. You will then see a dialog box that asks you to nominate the names of the layers on which pipes, pits and background are located, as shown in Figure 3.3. This is saved as a file **`Brisbane.dxf`**.

Using the drop-down list box, you can select the appropriate layers. Pits and pipes can be placed on the same layer if you wish. Once layers are selected, a number of information windows appear. The first one shown in Figure 3.4 allows pipe lengths to be automatically scaled off the DXF drawing, according to the length allocated to the first pipe for which full data is entered.

The *DRAINS* Main Window then appears with the drainage system and background shown as in Figure 3.5. This can be enlarged if necessary, using the Zoom tool. The colour of the background and its intensity can be changed using **the Background Colour…** option in the **View** menu. If the background has a much greater extent than the pipes in the model, *DRAINS* will reduce the field of view. This can be extended again using the **View** → **Extend Drawing Area…** option. Dummy pipes and pits can also be inserted to provide a large background, as shown to the left of Figure 3.5.

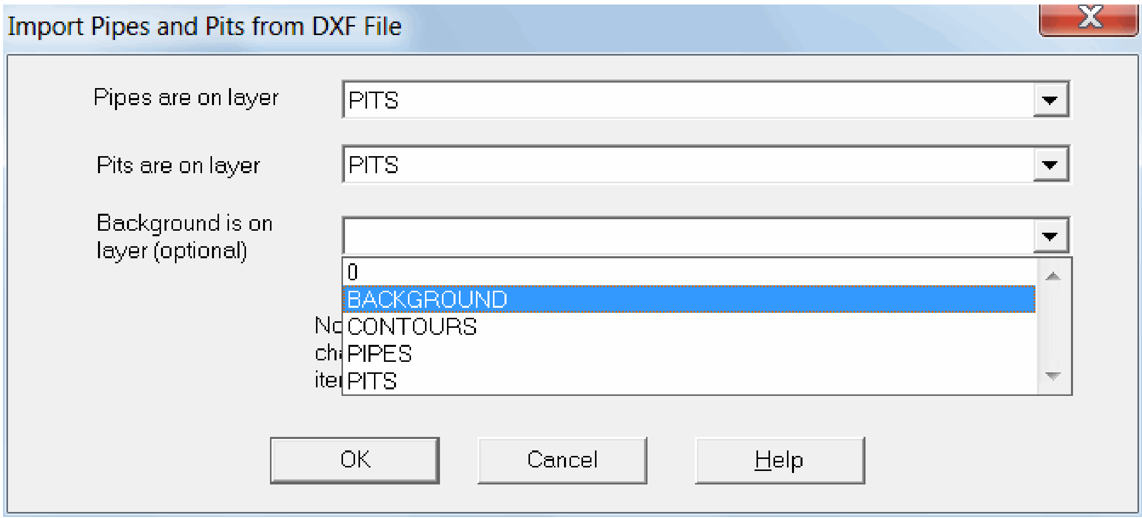


Figure 3.3 Layer Selection Dialog Box

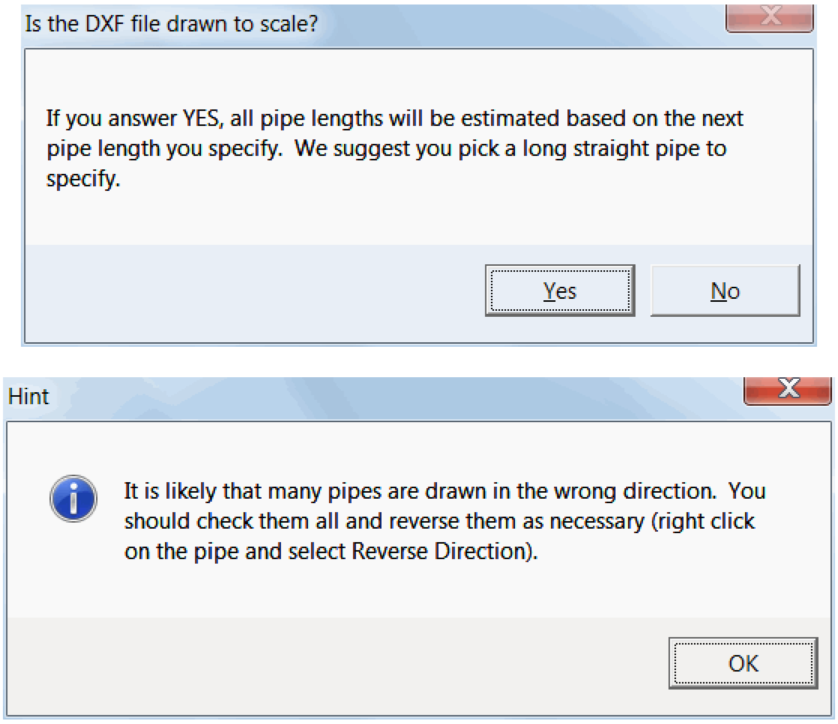


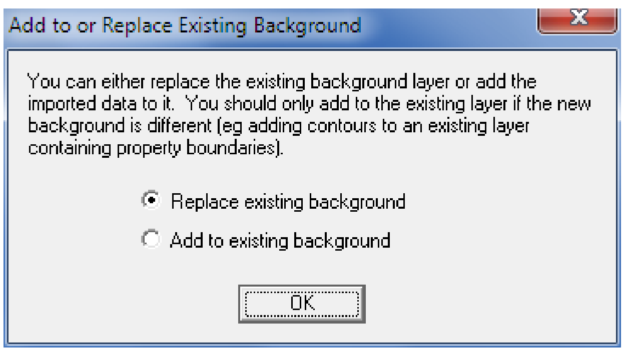
Figure 3.4 Messages in DXF Import Procedure

You must now enter information for pits and pipes, and draw in sub-catchments, overflow routes and outfall nodes, as shown in the example in Chapter 1. Directions of pipes will have to be changed if the pipes in the CAD drawing are drawn from 'the bottom up'.

Lettering for features such as street names can be brought into *DRAINS* from a CAD file if it is in an acceptable format. If AutoCAD is being used, text in the Standard style on a single line (created using Draw → Text ► → Single Line Text) can be transferred.

(b) Replacement of Backgrounds

It is possible to import a new background or to exchange the current background with another. Using the **File → Import → Import DXF background…** option brings up a dialog box from which a DXF file can be opened. When a file is selected, the window shown to the right appears.



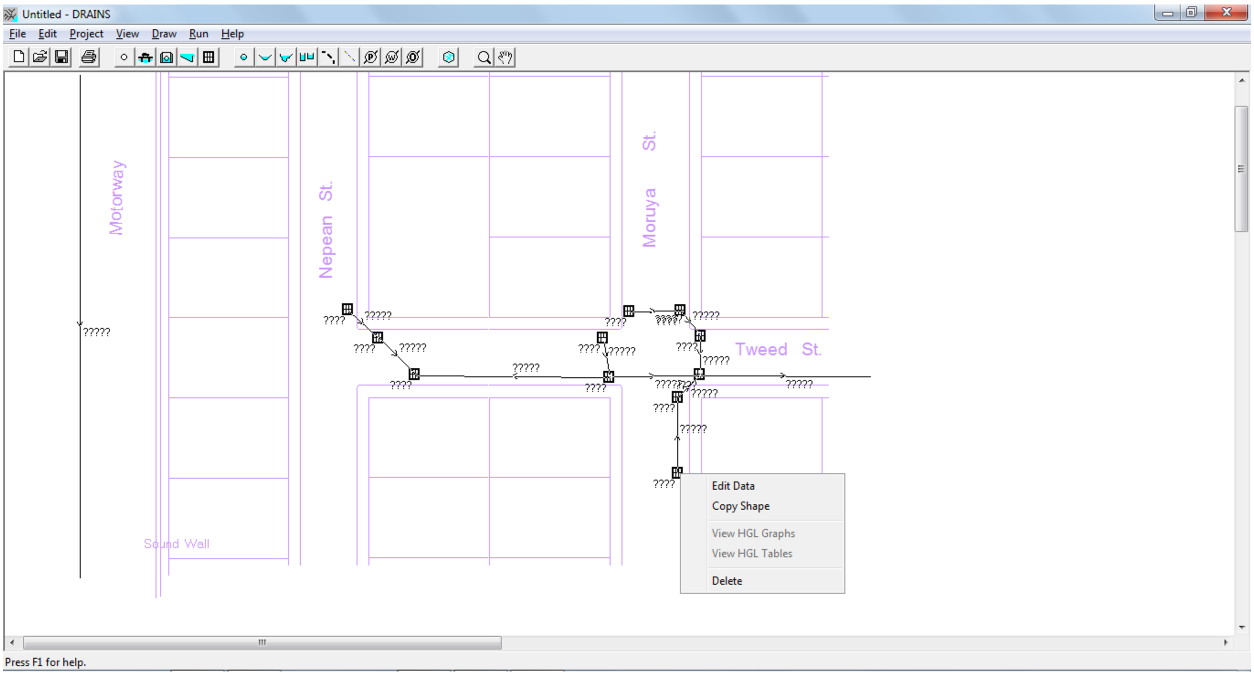


Figure 3.5 Imported DXF File Information

Note that if you replace a background, it does not open the dialog box shown in Figure 3.3 and will not transfer pits and pipes. All layers in the replacement CAD file will be shown. For example, if the Brisbane background is read in again, the contours and pipes will appear in the background. You must be careful that the replacement file only contains the layers that you want. This will probably involve the creation of an additional CAD file containing only those layers that you want to display.

If you have a *DRAINS* model without a background, you will be able to insert a background provided that it has a similar extent (in x-y coordinates) to the coverage of the x-y coordinates of the pits and nodes used in the model, which are displayed in the spreadsheet data output. Backgrounds can be inserted into models that include saved results.

3.2.3 Spreadsheet Imports

Information about a drainage system can also be imported from a spreadsheet file. Since this file will usually be created by outputting information from a *DRAINS* file, both the spreadsheet output and input processes are described later, in Section 3.5.4 of this chapter.

Some sets of information can be pasted into *DRAINS* property sheets for rainfall patterns, hydrographs, pits, detention basins, headwalls and culverts as columns from a spreadsheet.
A *DRAINS Utility Spreadsheet* and a *Generic Pit Inlet Capacity Sheet* are available to *DRAINS* Users, with the former being on the www.watercom.com site. Information from these can be pasted into *DRAINS* as shown in Figure 3.6.

3.2.4 GIS File Imports

(a) Importing ESRI (ArcView) Files

This process enables you to import data into *DRAINS* from one to six sets of ESRI or ArcView files, plus an optional background from a DXF file. The procedure is the reverse of the exporting process for ESRI files described in Section 3.5.5(a).

If you wish to model an existing drainage system in *DRAINS*, importing data from available ArcView records, you must edit these into the format required by *DRAINS*, described in Section 5.10.3(b). You can also scrutinise this format by exporting a small drainage system and examining the resulting DBASE tables. The six sets of files contain data for nodes (pits and outlets), pipes, overflow routes, sub-catchments, survey levels along pipe routes and the positions of other services along a pipe routes. Each set includes three files with SHP, SHX and DBF suffixes.

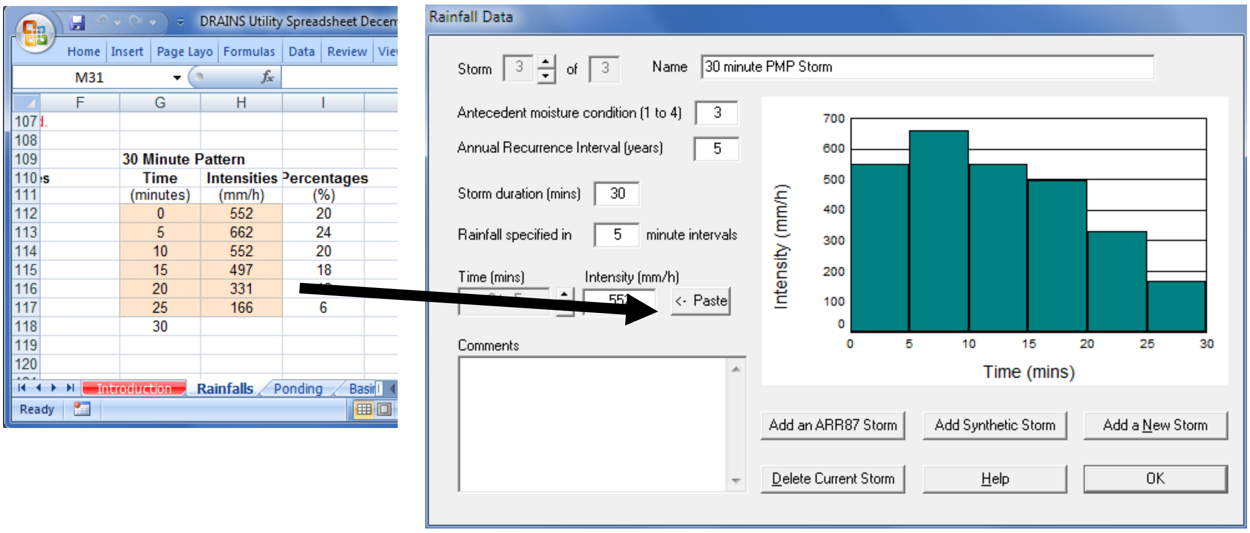


Figure 3.6 Transfer of a PMP Rainfall Pattern from a Utility Spreadsheet to *DRAINS* Rainfall Data

The transfer must include the files for nodes, but the rest are optional. In a first transfer, it is unlikely that all the information required by *DRAINS* will be available in the GIS. Information that is already in the GIS should be included in the files to be transferred. You can then choose whether to add additional data in these files, or to use dummy values and enter the required values later, in *DRAINS*.

The example shown in Figure 3. illustrates the process. The data for nodes (including pits and outlets) and pipes, each contained in a 'theme', needs to be entered in the data base tables shown in Figure 3.8, which can be created by editing in ArcMap or other GIS programs. A DXF file containing a background for the *DRAINS* model can be created from GIS layers.

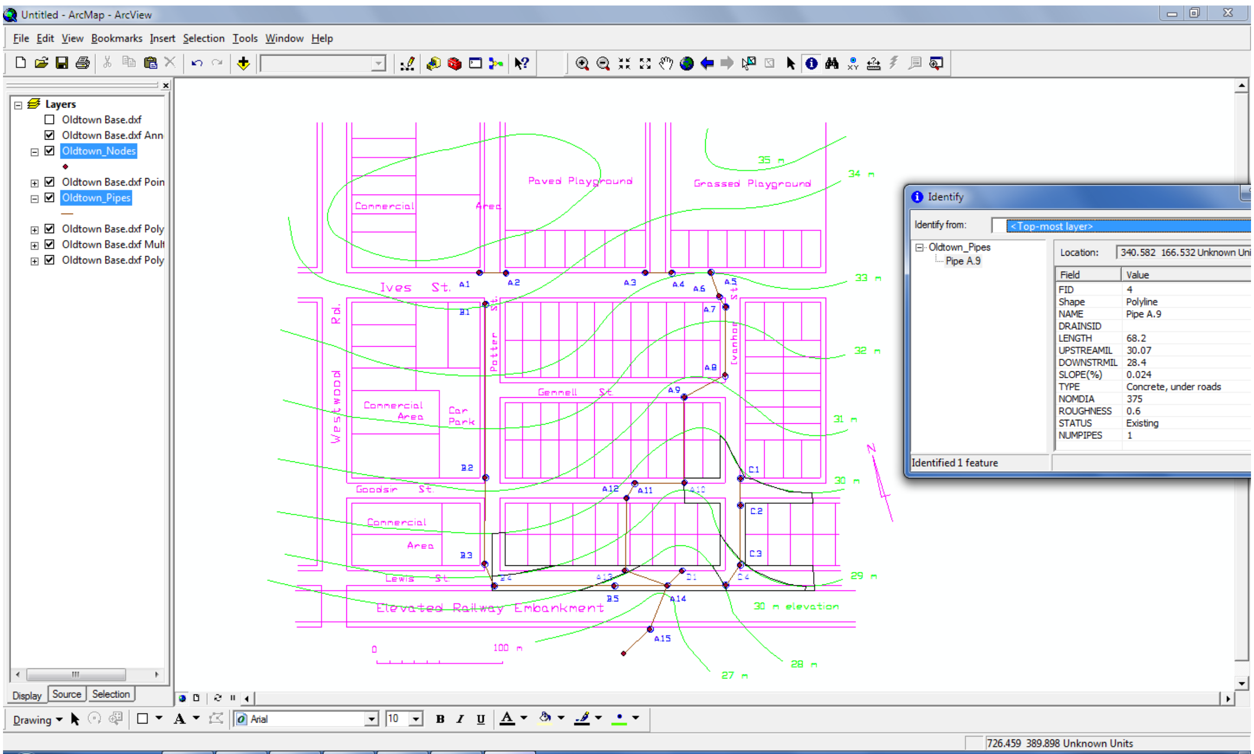
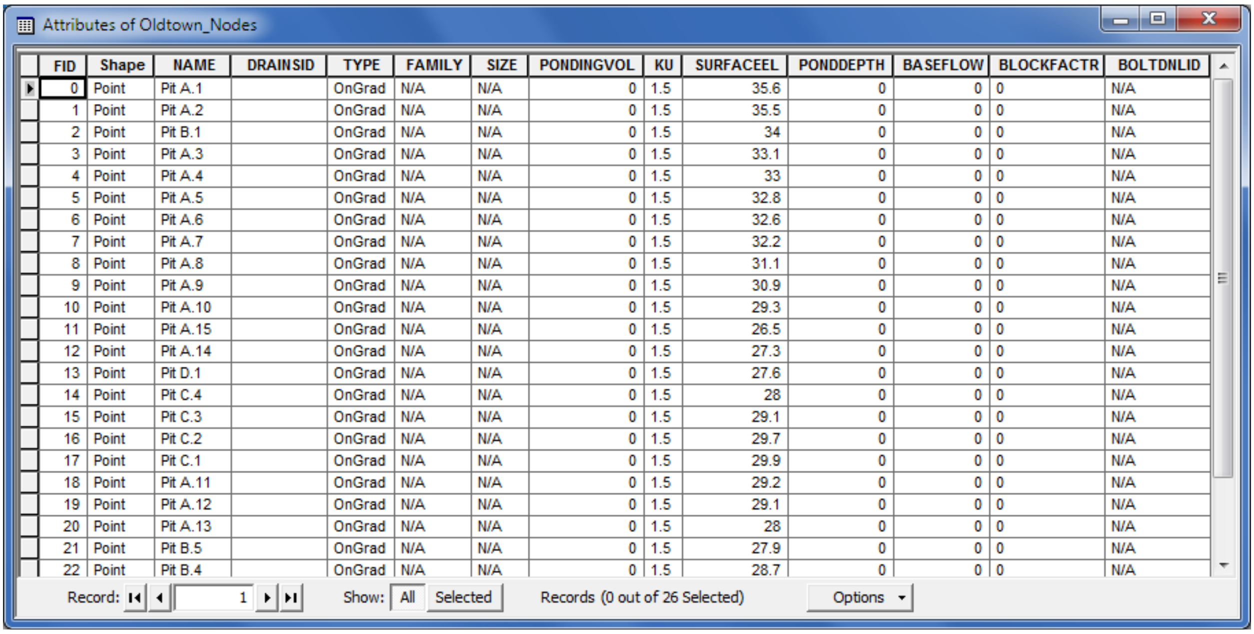


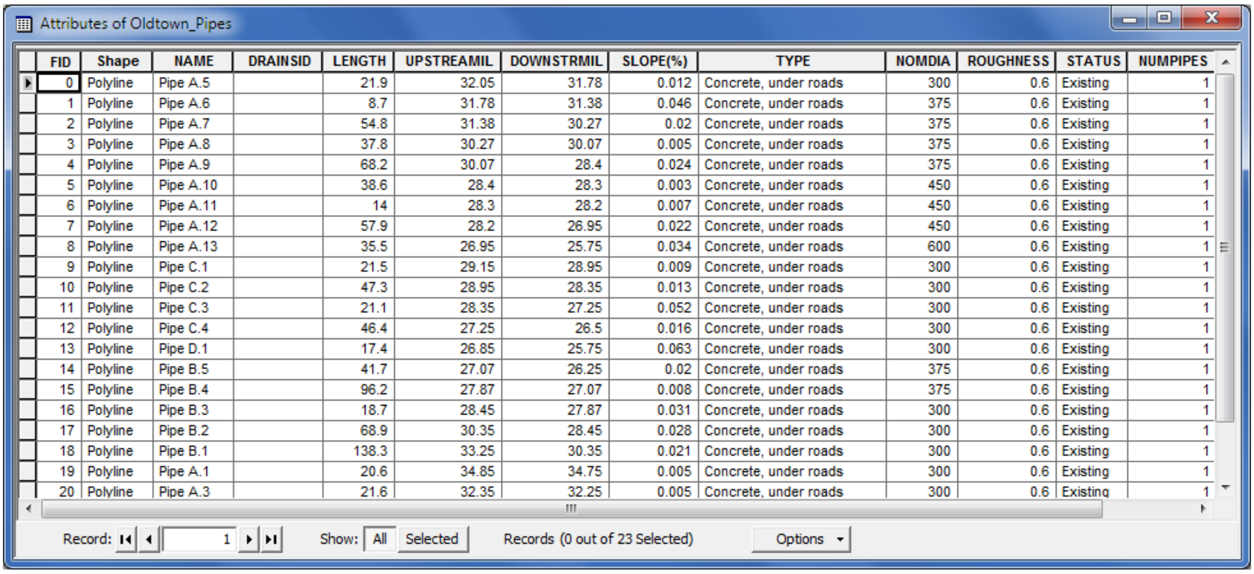
Figure 3.7 The 'Oldtown' Example in ArcMap

To make the transfer, you must place all files to be transferred into the same Windows folder, set up a *DRAINS* model with the ILSAX hydrological model and pit and pipe data bases that you require, and then use the **File -> Import -> ESRI Shapefiles…** option, which will display the message in Figure 3.9.

After entering 'Yes', you must select one of the ESRI files to be transferred, as shown in Figure 3.10 The transfer will then take place, and the pits and pipes will come into view, as shown in Figure 3.11.



FID	Shape	NAME	DRAINSID	TYPE	FAMILY	SIZE	PONDINGVOL	KU	SURFACEEL	PONDDEPTH	BASEFLOW	BLOCKFACTR	BOLTDNLID
0	Point	Pit A.1		OnGrad	N/A	N/A	0	1.5	35.6	0	0	0	N/A
1	Point	Pit A.2		OnGrad	N/A	N/A	0	1.5	35.5	0	0	0	N/A
2	Point	Pit B.1		OnGrad	N/A	N/A	0	1.5	34	0	0	0	N/A
3	Point	Pit A.3		OnGrad	N/A	N/A	0	1.5	33.1	0	0	0	N/A
4	Point	Pit A.4		OnGrad	N/A	N/A	0	1.5	33	0	0	0	N/A
5	Point	Pit A.5		OnGrad	N/A	N/A	0	1.5	32.8	0	0	0	N/A
6	Point	Pit A.6		OnGrad	N/A	N/A	0	1.5	32.6	0	0	0	N/A
7	Point	Pit A.7		OnGrad	N/A	N/A	0	1.5	32.2	0	0	0	N/A
8	Point	Pit A.8		OnGrad	N/A	N/A	0	1.5	31.1	0	0	0	N/A
9	Point	Pit A.9		OnGrad	N/A	N/A	0	1.5	30.9	0	0	0	N/A
10	Point	Pit A.10		OnGrad	N/A	N/A	0	1.5	29.3	0	0	0	N/A
11	Point	Pit A.15		OnGrad	N/A	N/A	0	1.5	26.5	0	0	0	N/A
12	Point	Pit A.14		OnGrad	N/A	N/A	0	1.5	27.3	0	0	0	N/A
13	Point	Pit D.1		OnGrad	N/A	N/A	0	1.5	27.6	0	0	0	N/A
14	Point	Pit C.4		OnGrad	N/A	N/A	0	1.5	28	0	0	0	N/A
15	Point	Pit C.3		OnGrad	N/A	N/A	0	1.5	29.1	0	0	0	N/A
16	Point	Pit C.2		OnGrad	N/A	N/A	0	1.5	29.7	0	0	0	N/A
17	Point	Pit C.1		OnGrad	N/A	N/A	0	1.5	29.9	0	0	0	N/A
18	Point	Pit A.11		OnGrad	N/A	N/A	0	1.5	29.2	0	0	0	N/A
19	Point	Pit A.12		OnGrad	N/A	N/A	0	1.5	29.1	0	0	0	N/A
20	Point	Pit A.13		OnGrad	N/A	N/A	0	1.5	28	0	0	0	N/A
21	Point	Pit B.5		OnGrad	N/A	N/A	0	1.5	27.9	0	0	0	N/A
22	Point	Pit B.4		OnGrad	N/A	N/A	0	1.5	28.7	0	0	0	N/A



FID	Shape	NAME	DRAINSID	LENGTH	UPSTREAMIL	DOWNSTRMIL	SLOPE(%)	TYPE	NOMDIA	ROUGHNESS	STATUS	NUMPIPES
0	Polyline	Pipe A.5		21.9	32.05	31.78	0.012	Concrete, under roads	300	0.6	Existing	1
1	Polyline	Pipe A.6		8.7	31.78	31.38	0.046	Concrete, under roads	375	0.6	Existing	1
2	Polyline	Pipe A.7		54.8	31.38	30.27	0.02	Concrete, under roads	375	0.6	Existing	1
3	Polyline	Pipe A.8		37.8	30.27	30.07	0.005	Concrete, under roads	375	0.6	Existing	1
4	Polyline	Pipe A.9		68.2	30.07	28.4	0.024	Concrete, under roads	375	0.6	Existing	1
5	Polyline	Pipe A.10		38.6	28.4	28.3	0.003	Concrete, under roads	450	0.6	Existing	1
6	Polyline	Pipe A.11		14	28.3	28.2	0.007	Concrete, under roads	450	0.6	Existing	1
7	Polyline	Pipe A.12		57.9	28.2	26.95	0.022	Concrete, under roads	450	0.6	Existing	1
8	Polyline	Pipe A.13		35.5	26.95	25.75	0.034	Concrete, under roads	600	0.6	Existing	1
9	Polyline	Pipe C.1		21.5	29.15	28.95	0.009	Concrete, under roads	300	0.6	Existing	1
10	Polyline	Pipe C.2		47.3	28.95	28.35	0.013	Concrete, under roads	300	0.6	Existing	1
11	Polyline	Pipe C.3		21.1	28.35	27.25	0.052	Concrete, under roads	300	0.6	Existing	1
12	Polyline	Pipe C.4		46.4	27.25	26.5	0.016	Concrete, under roads	300	0.6	Existing	1
13	Polyline	Pipe D.1		17.4	26.85	25.75	0.063	Concrete, under roads	300	0.6	Existing	1
14	Polyline	Pipe B.5		41.7	27.07	26.25	0.02	Concrete, under roads	375	0.6	Existing	1
15	Polyline	Pipe B.4		96.2	27.87	27.07	0.008	Concrete, under roads	375	0.6	Existing	1
16	Polyline	Pipe B.3		18.7	28.45	27.87	0.031	Concrete, under roads	300	0.6	Existing	1
17	Polyline	Pipe B.2		68.9	30.35	28.45	0.028	Concrete, under roads	300	0.6	Existing	1
18	Polyline	Pipe B.1		138.3	33.25	30.35	0.021	Concrete, under roads	300	0.6	Existing	1
19	Polyline	Pipe A.1		20.6	34.85	34.75	0.005	Concrete, under roads	300	0.6	Existing	1
20	Polyline	Pipe A.3		21.6	32.35	32.25	0.005	Concrete, under roads	300	0.6	Existing	1

Figure 3.8 ArcView Tables of Characteristics of Nodes and Pipes, ready for Import into *DRAINS*

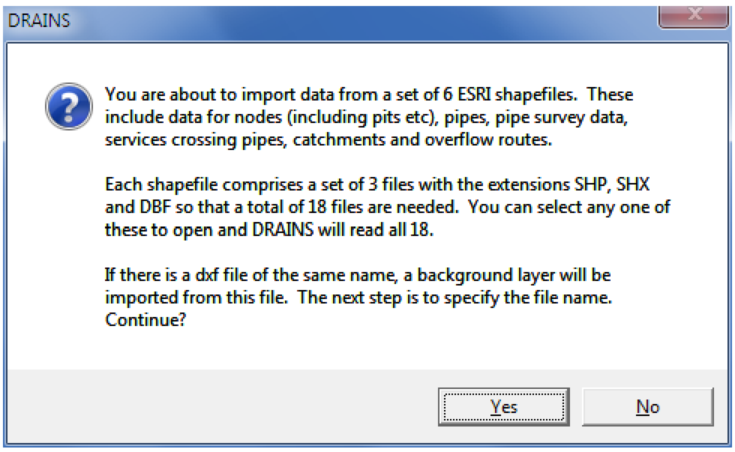


Figure 3.9 Shapefile Transfer Message

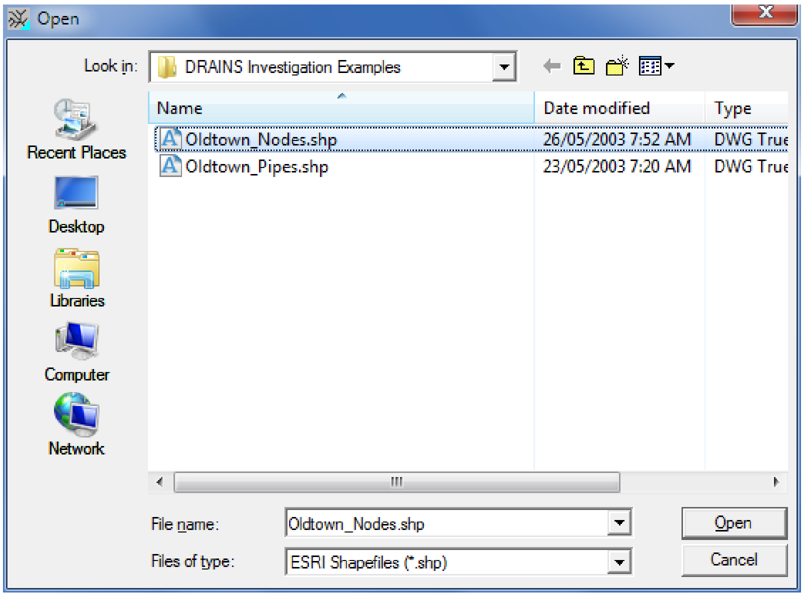


Figure 3.10 Choosing a Shapefile

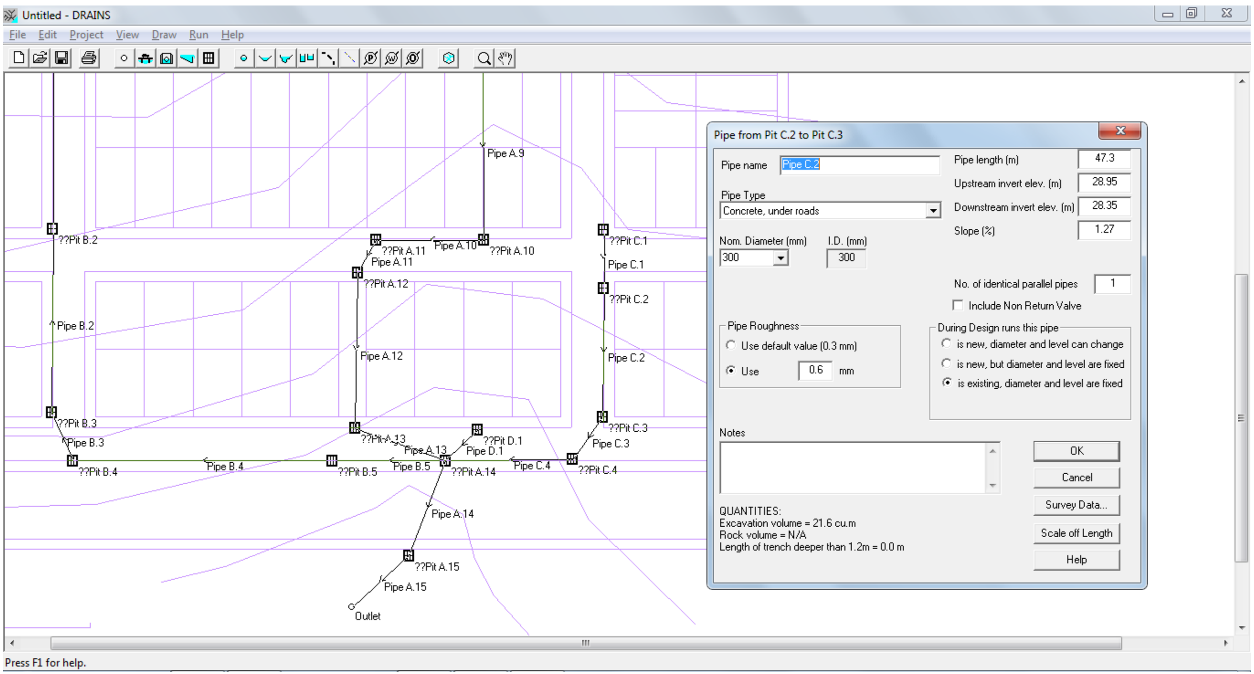


Figure 3.11 Transferred Data

(b) Importing MapInfo Files

This process enables you to import data into *DRAINS* from one to six sets of MapInfo files, plus an optional background from a DXF file. The procedure is the reverse of the exporting process for MapInfo files described in Section 3.5.5(b), and is similar to the ESRI transfer process described in the previous section of this chapter. The six sets of files cover nodes (pits and outlets), pipes, overflow routes, sub-catchments, location of ground levels along the pipe routes, and the location of other services along these routes.

To transfer MapInfo data to *DRAINS*, you need to edit the available MapInfo data into pairs of MID and MIF files in the format required by *DRAINS*, specified in Section 5.10.3(c). This is the same as the format generated in the export process that creates MapInfo files from *DRAINS* data, which you can see by exporting a small system and examining the resulting tables.

All the required information that is already in the GIS should be included in the files to be transferred. It is then a matter of choice as to whether you add additional data in these files, or enter dummy values, and enter the missing data later in *DRAINS*.

The following example illustrates the process, paralleling the ESRI file import example. Figure 3.12 shows the Oldtown System in MapInfo, with the data for one pipe being displayed. This can be set up in MapInfo or in a text editor. The corresponding node data is similar.

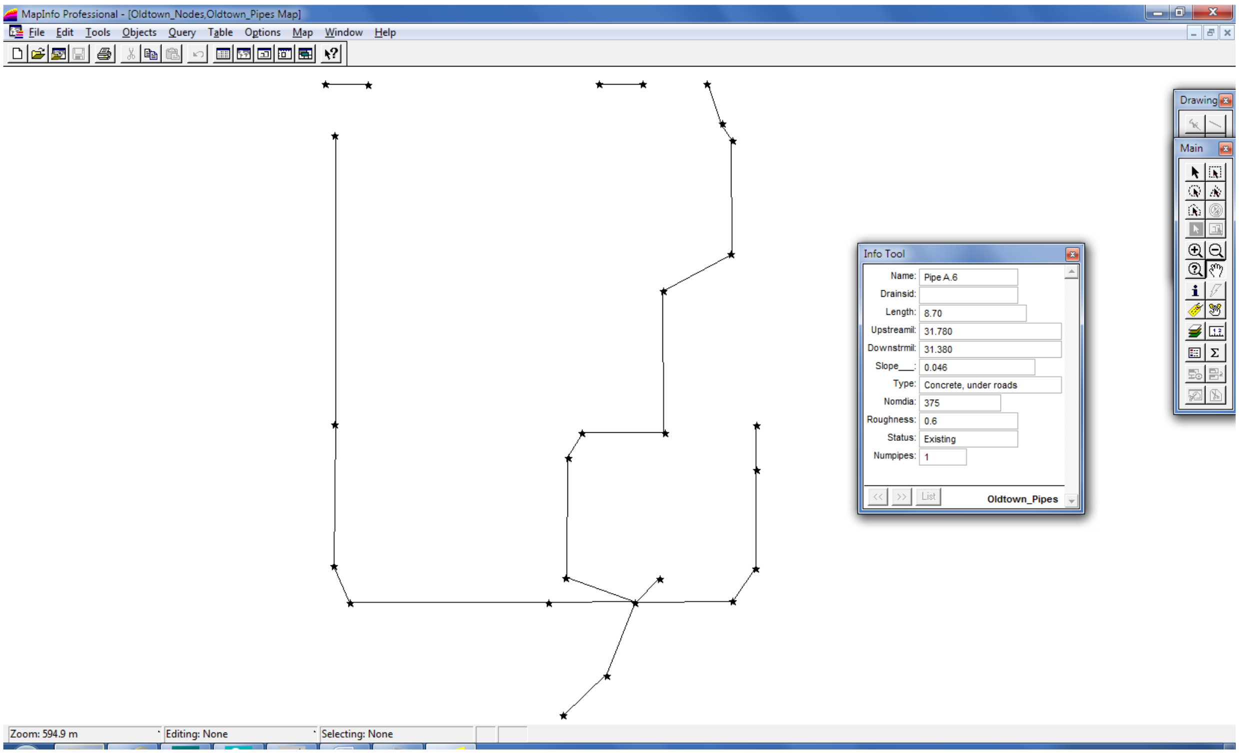
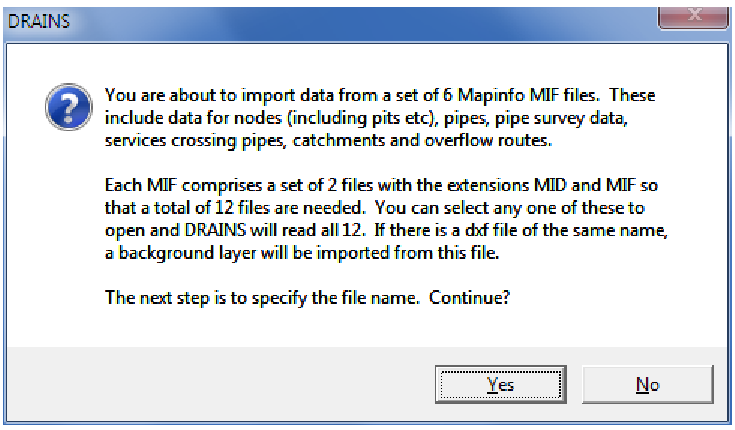


Figure 3.12 The 'Oldtown' Example in MapInfo

From the MapInfo layers, a DXF file containing a background for the *DRAINS* model can be created. This will appear in the same form as Figure 3.10.

To make a transfer, you will need to place all the files to be transferred into the same Windows folder, set up a *DRAINS* model with the ILSAX hydrological model and pit and pipe data bases that you require, and then use the **File -> Import -> MapInfo MIF files…** option, which will display the following message:



After you enter 'Yes', you must select one of the MapInfo MIF files to be transferred, as shown in Figure 3.13. The transfer will then take place, and the pits and pipes will come into view, in the same form as Figure 3.11.

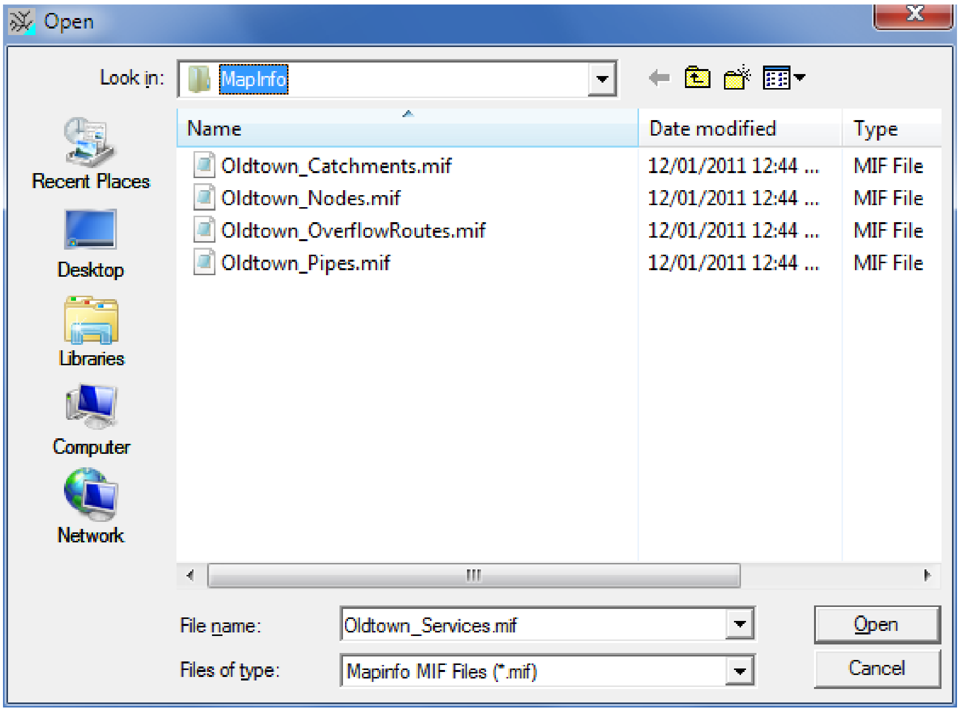
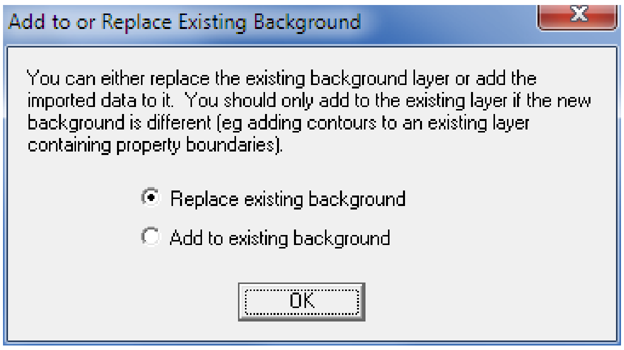


Figure 3.13 Choosing a MIF File

As with the ESRI transfers, with this setup it is possible to import a new or additional background. Using the **File -> Import -> Import DXF background…** option brings up a dialog box from which a DXF file can be opened. When a file is selected, the following window appears. When a choice is made, the background is replaced.



3.2.5 ILSAX File Imports

DRAINS is partly based on the ILSAX program that was used widely in Australia since 1986. Many Government organisations developed ILSAX files describing their drainage systems that could be converted to *DRAINS* files using the **Import ILSAX Files …** option in the **File** menu. However, there have been changes to *DRAINS* that mean that now it is hardly worthwhile to make transfers by these means. These changes include the use of a different type of pit inlet capacity relationship and the omission of the ILLUDAS type pit that was employed in the transfer (refer to the *DRAINS* Help system).

It is therefore recommended that this feature not be used, and that models be created by other means. However, the transfer facility is still available, and instructions are available in the *DRAINS* Help system under the topic 'Importing ILSAX files'.

3.2.6 Merging Files

There is an option in the **File** menu to merge *DRAINS* files together. Since this first involves an output process, it is described in Section 3.5.8.

3.2.7 Transferring to and from CAD Programs

Drafting programs such as AutoCAD, Microstation, IntelliCAD, Bricscad and TurboCAD can be used for creating the network geometry. In the drawing, all pipes must be on a layer and all pits on a separate layer. Pipes must be drawn as lines and pits as circles. (If the drawing uses other symbols for pits, a separate layer should be created, with a circle over each pit.) The file should be saved in DXF format. At the time of import to *DRAINS* you will be asked to nominate the respective layers, as described in Section 3.2.2 using the **File → Import ► Import DXF file…** command.

3.2.8 Transferring Data to and from the 12d Program

Data for setting up *DRAINS* models can be imported directly from the 12d digital terrain modelling program. After design and analysis have been carried out in *DRAINS*, using the ILSAX or ERM models, the resulting system information can be returned to 12d for further analysis and plotting. An important requirement is to ensure consistency in pit and pipe names used. The procedure does not work with DRAINS rational method calculations.

The following instructions relate to 12d, Version 7. For more current information contact 12d directly at http://www.12d.com/aus/service_and_support/technical_support/contact_your_local_support/australia/. Assuming that you have set up a drainage system in 12d, defining pits, pipes, sub-catchments and overflow routes, the steps involved in the transfer process are:

(a) While 12d is open, start up a *DRAINS* model with the required hydrology, rainfall, pipe, pit and overflow route data bases. Open the pit data base in the *DRAINS* **Project** menu and then close this, clicking OK. When asked if you wish to save the altered data base, reply 'Yes'. (This ensures that the required data base is stored in a file that 12d can access.)

(b) Next, in 12d open the dialog box selected from the menus, **Design → Drainage-Sewer → More → Drains to drainage 4d → drains**. This appears as shown in Figure 3.14.

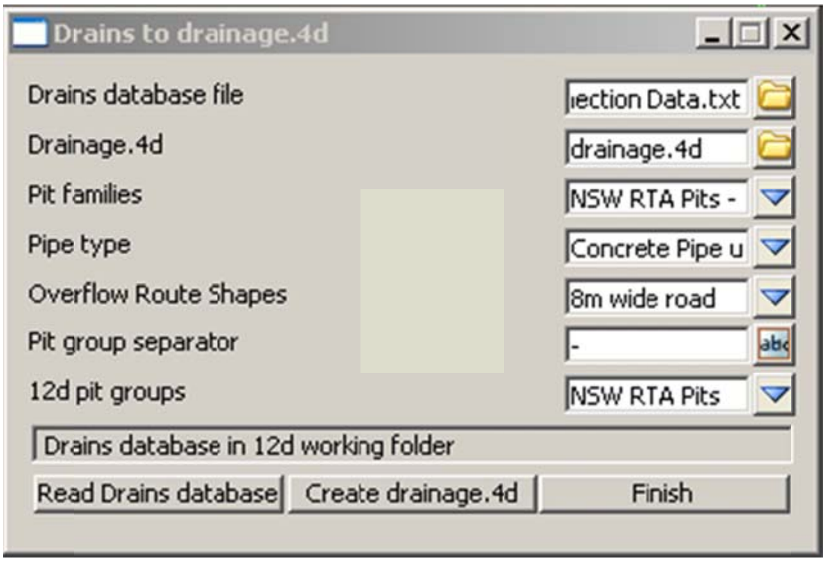
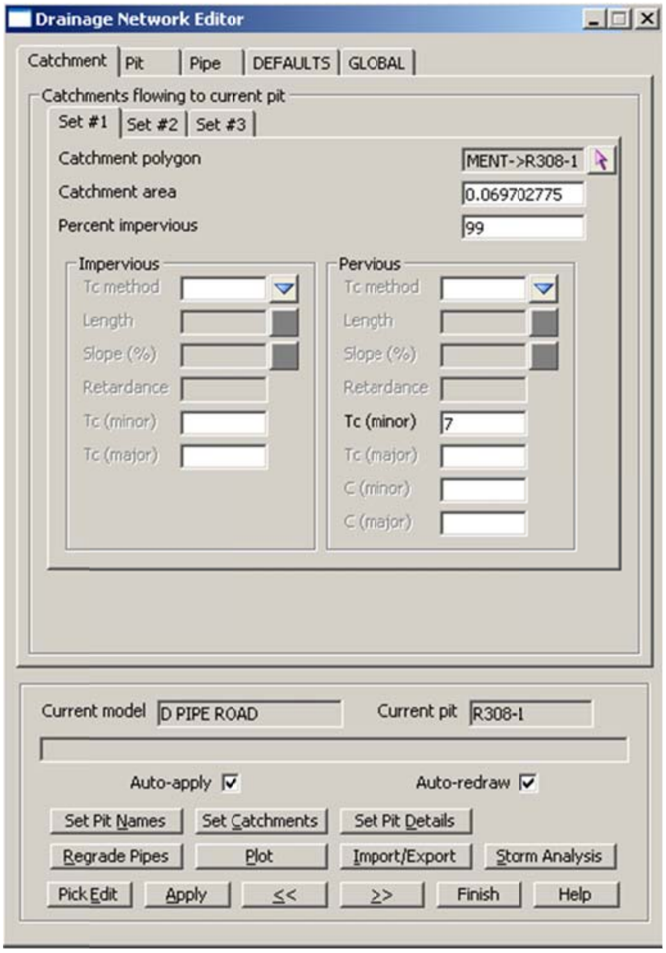


Figure 3.14 *DRAINS* Transfer Dialog Box Specifications in 12d

Check the databases making sure that the required *DRAINS* pipe and pit relationships appear. Click the **Read Drains database** button and check the displayed information and the pit group separator. Separators ',' or '-' are used in the names contained in different *DRAINS* pit data bases. If the data is not what you want, return to Step (a).

(c) Then open the window **Design → Drainage-Sewer → Drainage Network Editor**, shown as Figure 3.15. From this you can check define sub-catchments, pits, pipes and overflow routes using 12d procedures. Set appropriate defaults and use the **Set Pit Names** button to provide a set of unique pit names. Then press **Set Pit Details** and **Set Catchments** and nominate the **Regrade Pipes** option.

(d) Now the transfer can be made using the **Import/Export** button on the Drainage Network Editor, which opens the dialog box shown in Figure 3.16. For I/O format, select 'Drains Clipboard **-** Ver 5 ILSAX' or 'Drains Clipboard - Ver 5 Rational' depending on the hydrological model you are running in *DRAINS*. Click the **Run** button.



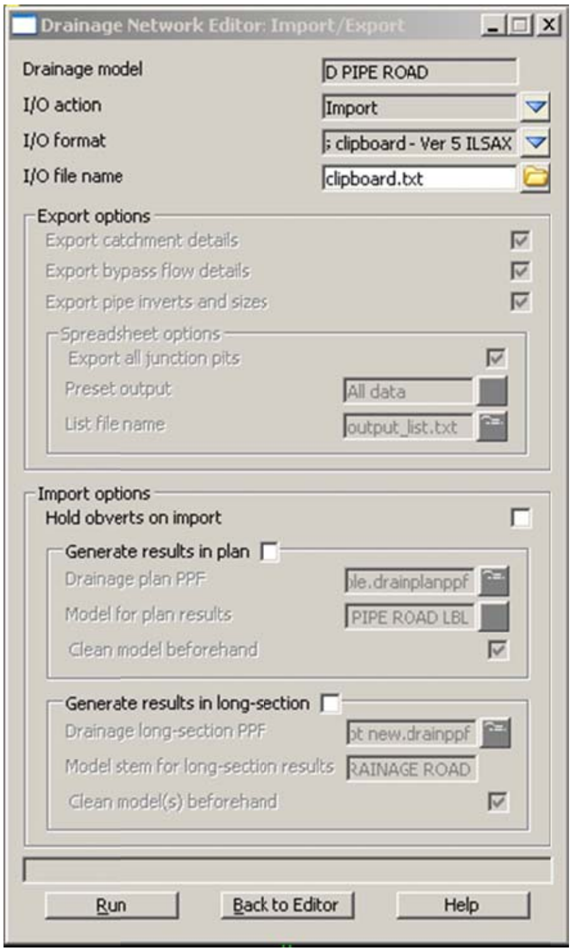


Figure 3.15 12d Drainage Network Editor **Figure 3.16 12d Import/Export Window**

(e) Now switch to the *DRAINS* model noted in Step (a), and from the **Edit** menu, select **Paste Data from Spreadsheet**. The model should then appear, ready for a Design run.

(f) Run the model in *DRAINS*, using ILSAX or rational method hydrology and the standard or premium hydraulic models. Inspect the results, and when satisfied, send data to the Clipboard using the **Copy Data to Spreadsheet** option in the **Edit** menu.

(g) Using the Import/Export button in the 12d Drainage Network Editor, bring the data back to 12d.

(h) Going back to *DRAINS*, press **Edit → Copy Results to Spreadsheet**, and in 12d press the Import/Export button again to bring the remainder of the required information into 12d. (Note that this reverse data transfer must be done in two stages, first data and then results.)

For further details, contact 12d.

3.2.9 CADApps Advanced Road Design Link

The Advanced Road Design (ARD) program is used inside Autodesk Civil 3D. It has purpose-built tools for creating drainage network geometry and assigning the catchment/overflow route/surface profile geometry information required by *DRAINS*. ARD was developed by Peter Bloomfield and CADApps (www.cadapps.com.au, www.civilsurveysolutions.com.au). This transfer procedure works when *DRAINS* has ILSAX or ERM specified, but not for the rational method. When this is specified as the hydrological model, the links to ARD in the File menu, mentioned below, do not appear.

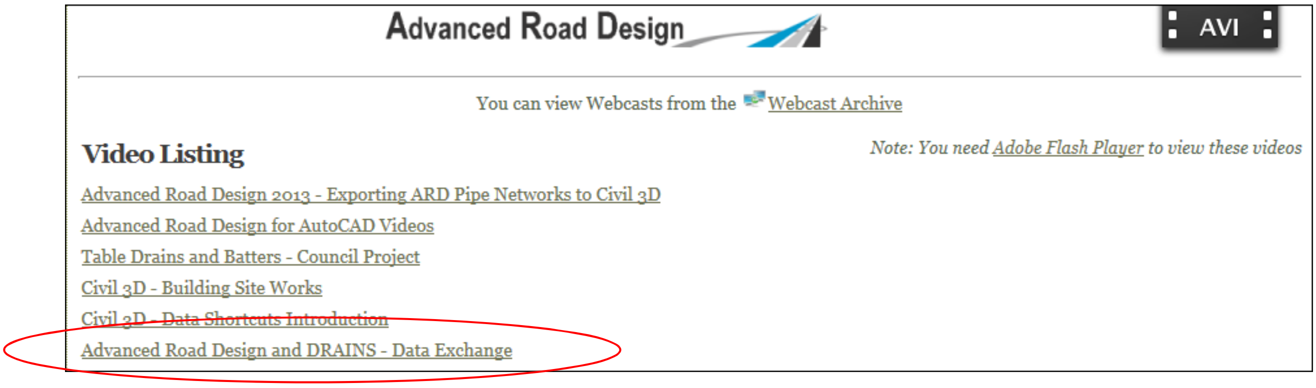
To make a transfer, from the ARD 'Drainage' menu use the command:

Drainage ► Data Exchange ► Write to Drains

With Civil 3D the data is written to the **Drains-n.mdb** file in the DrawingName_Data\AdvRoads directory under the directory holding the drawing file.

In DRAINS use the **File** → **Import ► Import Advanced Road Design file…** command to import the data. After making a run in *DRAINS*, use the **File** → **Export ► Advanced Road Design file…** command

to export the data. This command writes the Design data back to the Advanced Road Design data file from where it is exported back to the Advanced Road Design data file for plotting with the **Drainage ► Data Exchange ► Read in Drains data** command. For further details, view the educational video at www.civilsurveysolutions.com.au,



or contact Andrew English on (03) 9568 0077 or andrew.english@ccivilsurveysolutions.com.au.

3.2.10 Transferring from MXROADS

The Bentley MX ROAD software has a connection to *DRAINS* that operates in the same way as the Advanced Road Design procedure described in the previous section. The commands:

File → **Import ► Import Advanced Road Design file…**

File → **Export ► Advanced Road Design file…**

can be used to import and export MXROADS files. For detailed information, contact support at Bentley. Like the other connections, this does not work when DRAINS has a rational method hydrological model. It operates when the DRAINS model has an ILSAX or ERM model specified.

3.2.11 Transferring from CatchmentSIM

CatchmentSIM, developed by Chris Ryan (2005), is a program that manipulates topographic data to define catchments and to determine catchment characteristics. Starting with data in a 3-dimensional vector format such as MID/MIF or TIN files, CatchmentSIM converts these to a raster grid, from which catchments and sub-catchments can be defined. For urban catchments, barriers to flow along fences and road crowns can be specified, and the sub-catchments derived reflect these.

This information can be used to develop *DRAINS* models. For further information, contact Catchment Simulation Solutions at www.csse.com.au.

3.2.12 Setting Up New Pipe, Pit and Overflow Route Data Bases

New data bases can be established using the **Default Data Base** Option in the **Project** menu. This opens the dialog box shown in Figure 3.17, from which a base can be selected from the **.db1** files stored in the `C:/Program Files/Drains/Program` folder. This is followed by a warning indicating that the default **.db1** file, `Drains.db1`, will be overwritten.

Note that this can only be done with a *DRAINS* file that has an empty main window. Once components are entered, the only way to add pipe or pit types is by hand. In addition, it is not possible to delete pipe and pit types in this situation, though their characteristics can be edited and changed. (**.db1** files are related to the new pit data bases and **.db** files to the older system described in Section 2.4.6.)

An additional feature, implemented through the **Import ► DRAINS Database (DB1) File…** option in the **File** menu can be used to add extra pipe, pit and overflow route types to a data base, as described in Section 2.4.5.

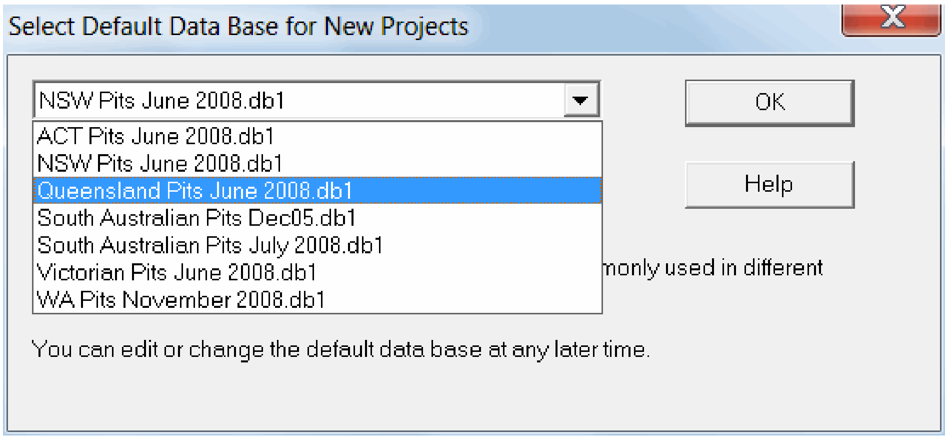


Figure 3.17 Default Data Base Dialog Box

3.3 Display Options

3.3.1 Introduction

DRAINS provides several options for viewing data on screen in addition to usual Windows facilities such as scrolling bars. The options available before calculations are performed are demonstrated in this section using the **`Toowoomba Estate.drn`** example that is ready to run in Design mode, which will define the pipe diameters and invert levels.

3.3.2 Screen Presentation Options

You can vary the way that a drainage system is presented on screen using options that are mainly included in the **View** menu (Figure **3.18**).

(a) Customise Text

The **Customise Text …** option at the top of the **View** menu produces the dialog box shown in Figure 3.19. By selecting options here, you can change the information provided, as indicated in Figure 3.20. Many choices are only available after a Design or Analysis run. The custom display numbers are coloured purple to distinguish them from names of components (black) and numerical outputs (black, green, blue and red).

This dialog box can also be opened by right-clicking on the name of any component, though not the component itself.

(b) Index Sheet

Selecting **Index Sheet** from the *DRAINS* **View** menu produces the view of the system shown in Figure 3.21. The rectangle represents the screen size. Placing this 'mask' in a certain position and clicking sets the screen to that position, as shown in Figure 3.22.

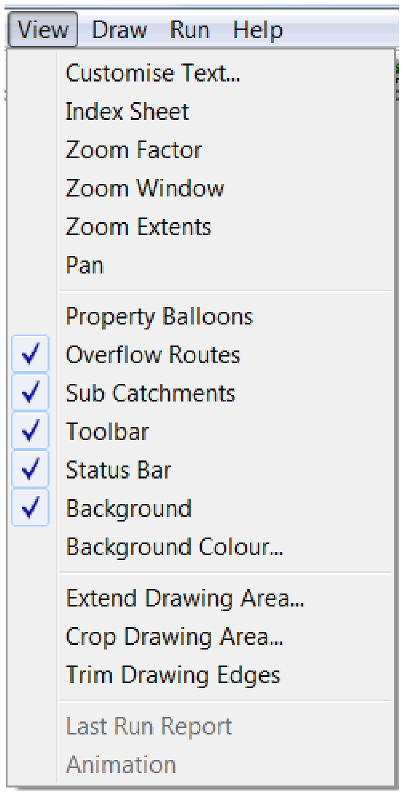


Figure 3.18 View Menu

(c) Zoom

There are three zoom options for enlarging or reducing the image in the Main Window. The **Zoom Factor**, which is also available through a button on the Toolbar, changes the cursor to a magnifying glass, which you should place over the area to which you wish to zoom. Clicking on this opens the dialog box shown in Figure 3.23, in which you can nominate the magnification. If you accept the default value of 1.5, an enlarged presentation is obtained. Entering a factor less than 1 reduces the size of the system, but the size of lettering remains the same.

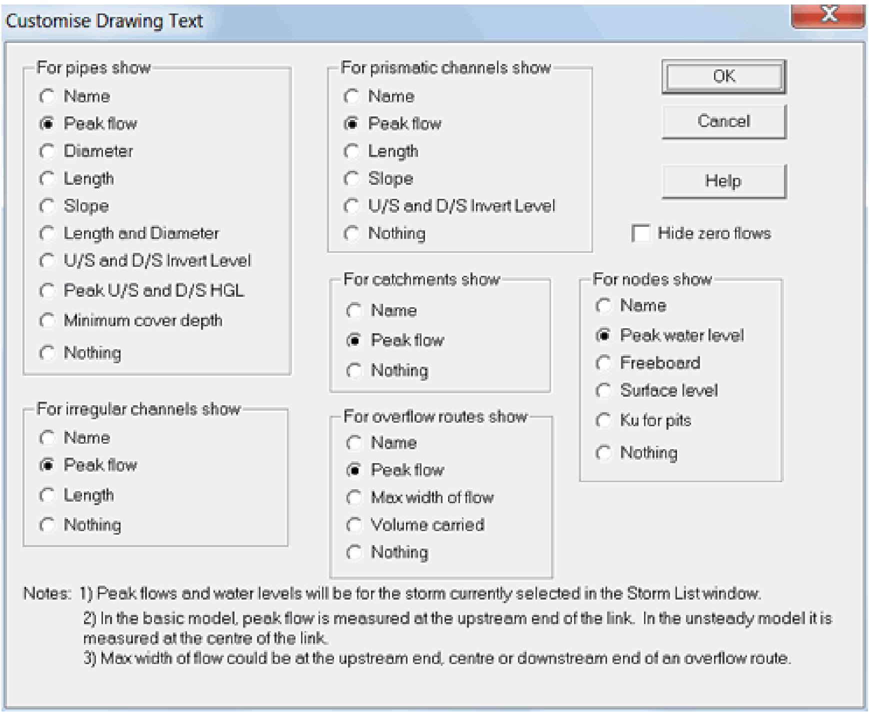


Figure 3.19 Dialog Box for Customising or Changing the Text Displayed

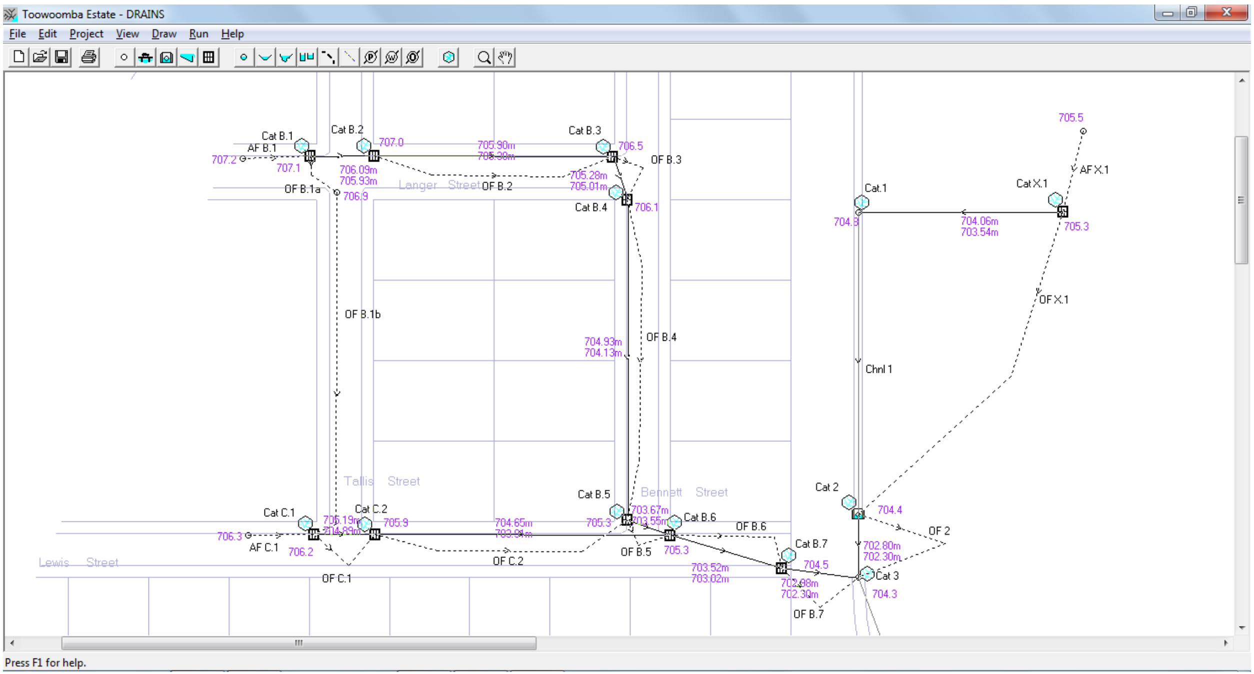


Figure 3.20 Drainage System with Surface Levels (coloured purple) replacing Pit Names and Upstream and Downstream Invert Levels replacing Pipe Names

The wheel on a mouse can also be used to zoom in and out of *DRAINS* models. To pan, you can press the **Pan** button on the Toolbar, or the sliding bars on the margins. In large drainage systems, you can use the Index Sheet facility described in the previous section.

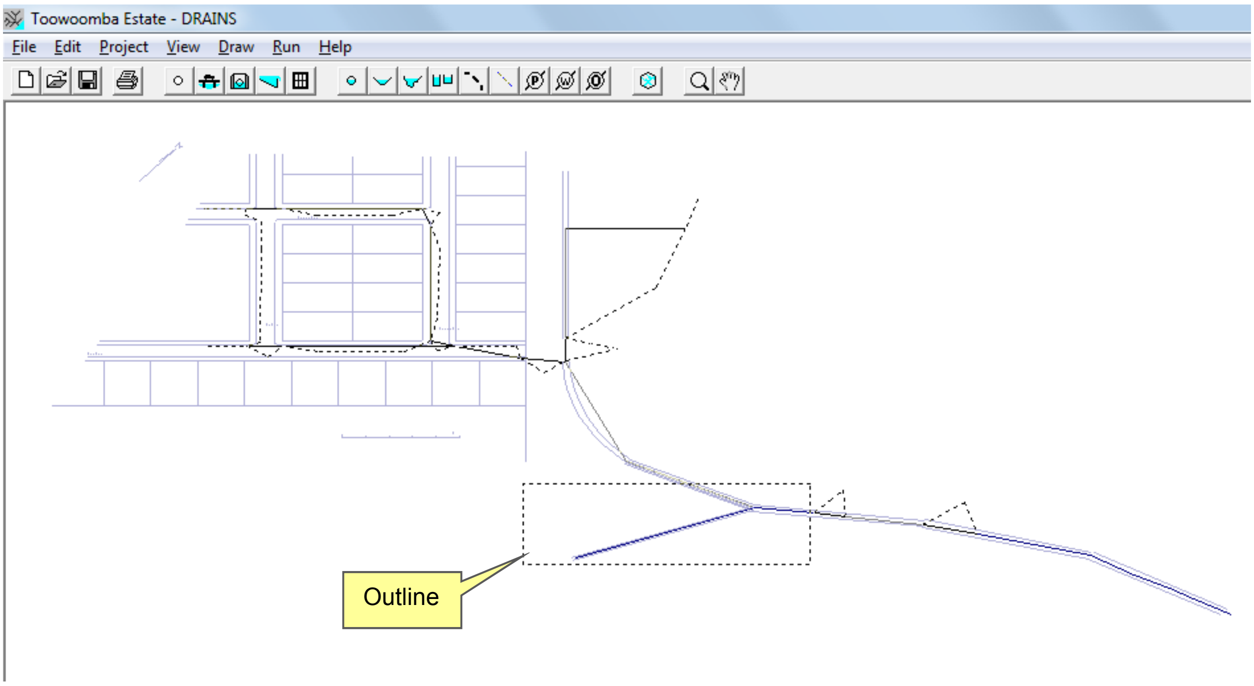


Figure 3.21 Index Sheet View

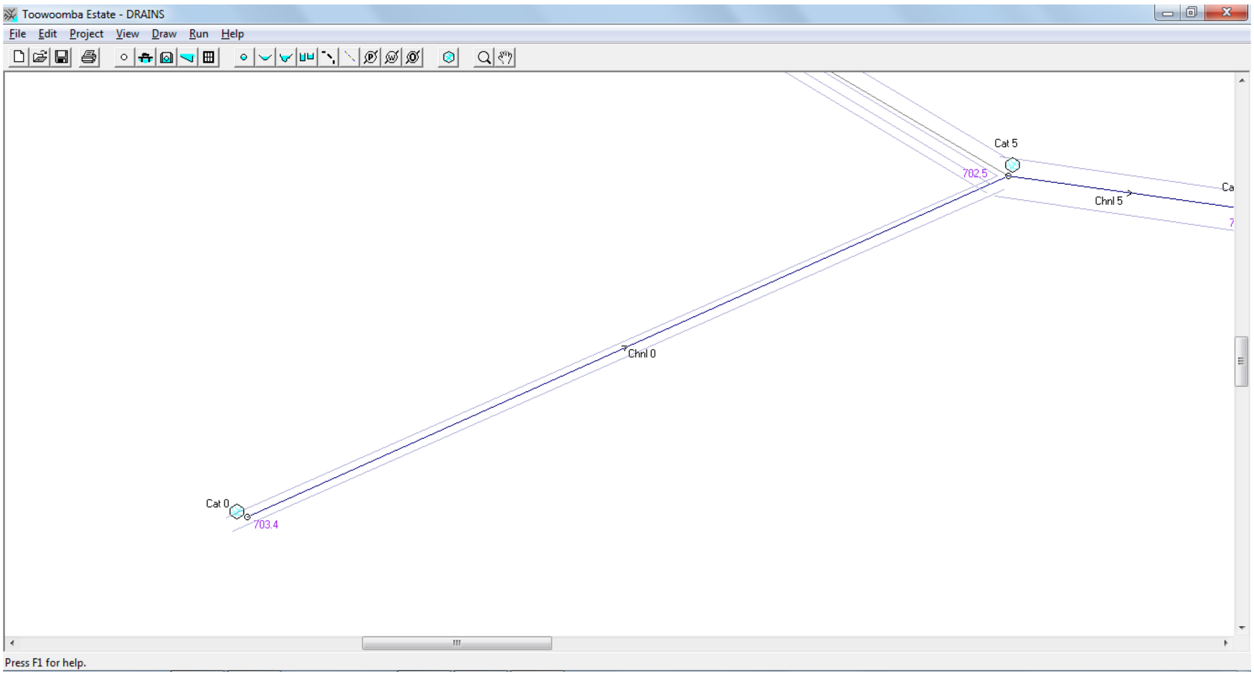


Figure 3.22 Toowoomba Pipe System selected using the Index Sheet

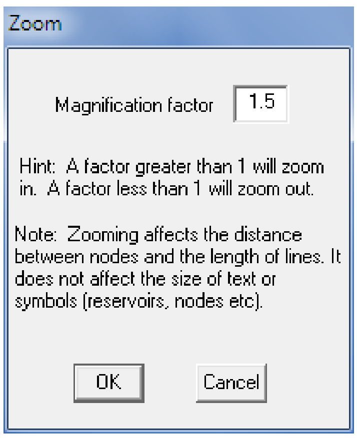


Figure 3.23 Zoom Window

The **Zoom Window** option in the **View** menu changes the cursor to crosshairs that can be used to define the rectangular area that is to be enlarged. When the mouse button is released, the enlarged area fills the Main Window.

The **Zoom Extents** option zooms out, but not to the full extent of the model. It can provide the desired extent when applied a number of times.

(d) Property Balloons

These can be switched on and off by clicking on **Property Balloons** in the **View** menu.

(e) Description Option

Note that the Main Window area includes a title block in the lower right corner. Text can be inserted into this block using the **Description…** option in the **Project** menu, which opens the property sheet shown in Figure 3.24. Comments and lines for the title block can be entered. If no block is required, the three TITLE BLOCK lines can be made blank.

(f) Removing Items from View

Facilities like the Status Bar at the bottom of the Main Window and components such as sub-catchments can be removed from the window if desired, using the options in the central part of the **View** menu.

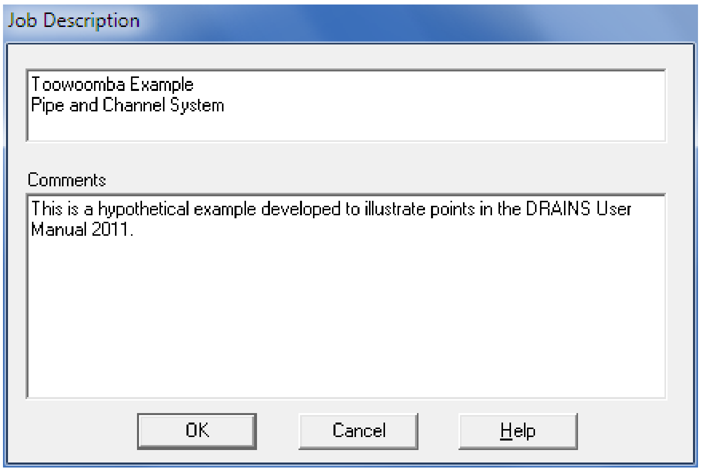


Figure 3.24 The Description Property Sheet

(g) Changes to the Main Window Coverage

The Drawing Area can be extended at the four corners, cropped (reduced selectively) or trimmed all round, using options in the **View** menu – **Extend Drawing Area ...**, **Crop Drawing Area ...**, and **Trim Drawing Edges**.

(h) Pop-Up Menu Displays

The pop-up menus opened by right-clicking on an object are the main means of presenting results of calculations on-screen. They also provide some information prior to calculations. Two displays from the Toowoomba example are shown in Figure 3.25.

3.4 Run Options

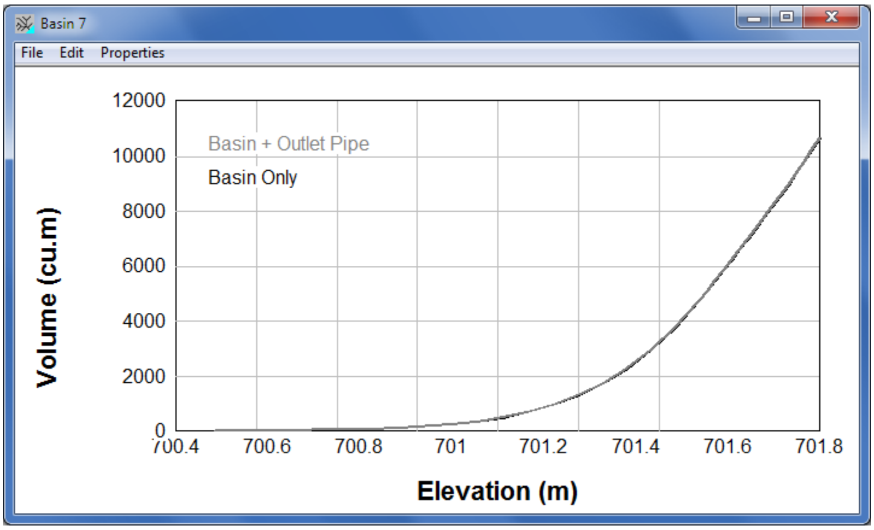
3.4.1 Design and Analysis Runs

In the **Run** menu shown in Figure 3.26 there are at least three run options:

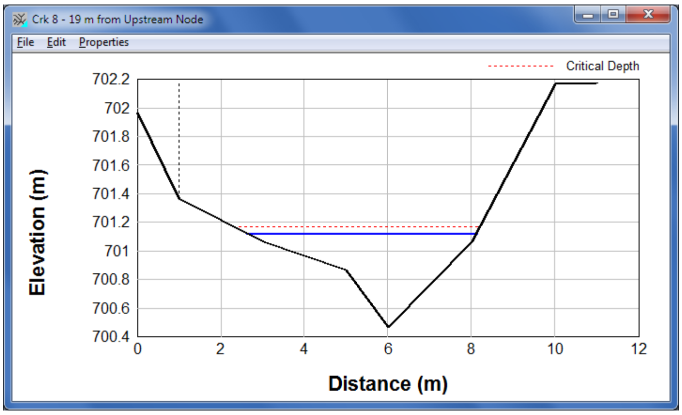
(a) the **Analyse major storms (standard hydraulic model),**

(b) the **Analyse minor storms (standard hydraulic model),**

(c) the **Design** option.



Detention Basin Elevation-Storage Relationship Display



Irregular Channel Cross-Section Display

Figure 3.25 Sample Displays from the Pop-Up Menus for Components

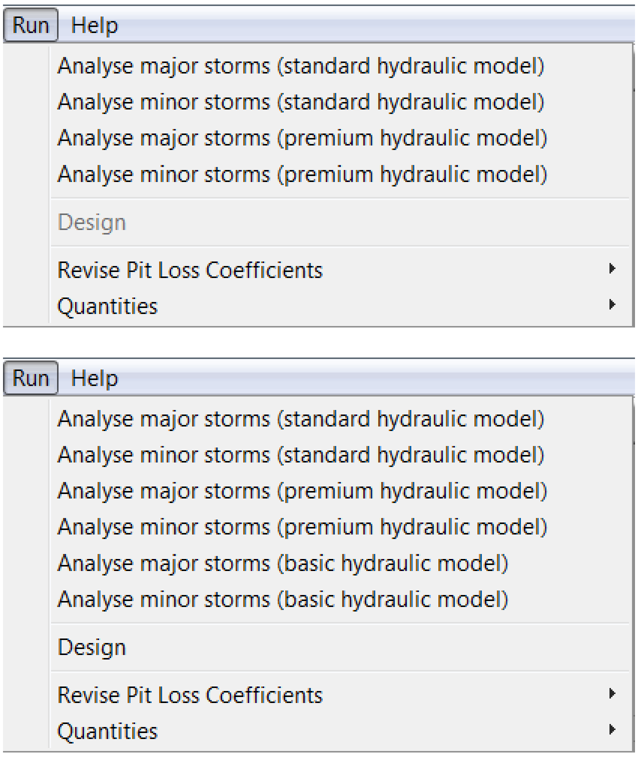


Figure 3.26 Run Menus for New *DRAINS* Models and for Older Models

If the premium hydraulic model is enabled by the hardware lock being used, there are two more options:

(d) the **Analyse major storms (premium hydraulic model),**

(e) the **Analyse minor storms (premium hydraulic model),**

and, if the model was created prior to the end of 2010, there are the options:

(f) the **Analyse major storms (basic hydraulic model),**

(g) the **Analyse minor storms (basic hydraulic model).**

There is also the **Design** option that sets pipe sizes and invert levels, and options for revising pit pressure change factors and outputting pipe quantities.

The alternative hydraulic models are described in Sections 4.2.7 and 0. The standard model that replaces the obsolete basic model applies unsteady flow calculations to pipes and open channels, but not to overflow routes. The premium model applies the unsteady calculations to all three types of conduits. The models can be run with either the set of minor or the set of major storms established in the rainfall inputs using **Select Storms ► Minor storms** or **Select Storms ► Major storms** options in the **Project** menu (see Section 2.4.4).

When any of the above options are chosen, *DRAINS* launches into a run. There may be warnings and a request to use parallel processing. Once these are noted are acted upon, the run begins. Rational method calculations are quick because only peak flows are generated and there are no unsteady flow calculations. The simulation runs used with the other, hydrograph-producing models will take longer to run, and will produce much more comprehensive results.

Analysis runs treat all pipes as fixed, and do not alter the given pipe diameters and invert levels. Complex situations, such as pits with the invert of the outgoing pipe being higher than those of the incoming pipes, can usually be modelled.

For pipes that have the specification shown in Figure 3.27, the **Design** option selects pit sizes from the specified pit family for each pit, and defines the pipe diameters and invert levels for circular pipes. (Design cannot be performed with rectangular pipes.) If you have already specified invert levels, these will most probably be changed in a design. (In calculations, the second option in Figure 3.27 is treated exactly the same as the third, except that when *DRAINS* calculates quantities of soil volumes for excavation, volumes for pipes defined under Option 2 are included in the table of quantities along with those defined under Option 1; volumes for Option 3 pipes are not.)

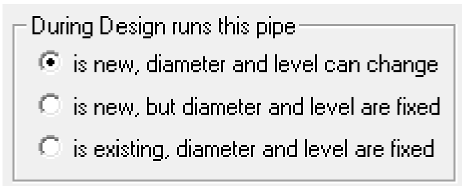


Figure 3.27 Specification of Pipe Types

DRAINS does not specifically try to design around existing pipes with fixed invert levels, so situations will be encountered where it is not possible to do this while obeying the restrictions set in the **Options** property sheet opened from the **Project** menu. In these cases, the invert levels at the downstream end of designed pipes may be specified as being lower than the existing pipe to which they connect.

The design method applied, based on the *Queensland Urban Drainage Manual* (Neville Jones & Associates et al., 1992) varies both pits and pipes to obtain an optimal result. It is possible to set the pit size and the pipe diameter and invert levels as fixed, using options in the Pit and Pipe property sheets. Both procedures allow for intermediate levels along a pipeline route between pits. These are considered when pipe invert levels are determined, allowing for minimum cover depths.

3.4.2 Run Logs

Following a run, *DRAINS* presents a log reporting on the results, as shown in Figure 3.28, indicating problems and possible causes. The first example shows a trouble-free run and the second one that has complex results.

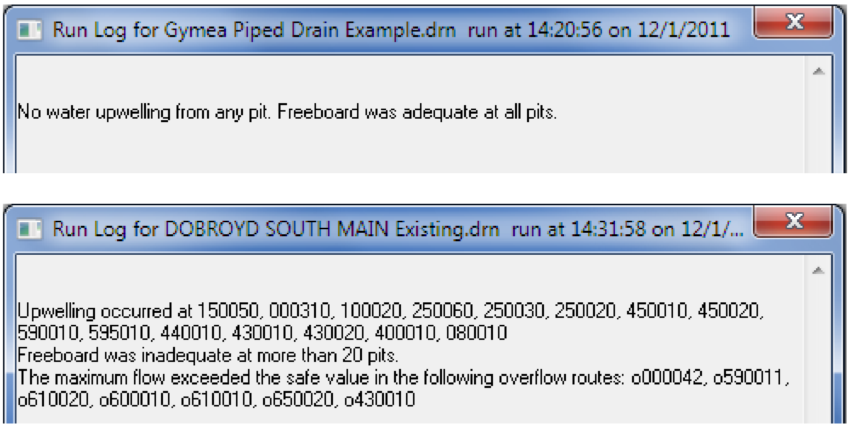


Figure 3.28 Examples of Messages Reporting Results from Design and Analysis Runs

The report must be closed (by clicking on the X at the top right of the window), but it can be recalled using the **Last Run Report** option in the **View** menu. The information in the log is also reproduced in the spreadsheet output for results.

3.4.3 Warning and Error Messages

DRAINS performs a number of checks as data is entered. One is to ensure that all the required data is provides. In some instances *DRAINS* requires values to be within certain ranges of expected values, in others it queries values that appear to be unusual. Warnings like those shown in Figure 3.29 also appear when a run is initiated, and after a run. It is important to heed these, and to try to eliminate the causes.

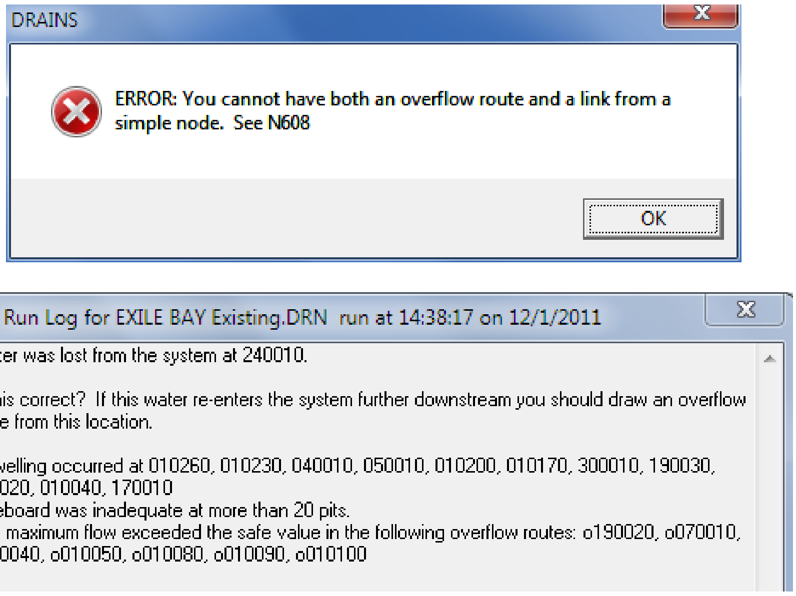


Figure 3.29 Warning Messages (see also Figure 3.28)

If a serious computational problem occurs, and *DRAINS* cannot resolve this, an error message may appear, and the program will shut down after this is closed. Sometimes such messages will request that you contact Watercom Pty Ltd to resolve the problem.

3.4.4 Options for Modifying Pit Pressure Change Factors

The **Revise Pit Loss Coefficients** option alters the pit pressure change coefficients using an algorithm based on an approximate relationship developed by Mills or a method based on the *Queensland Urban Drainage Manual*, QUDM (see Section 0). Before using these procedures, you must run *DRAINS* to obtain a set of flows and HGLs, as shown in Figure 3.30.

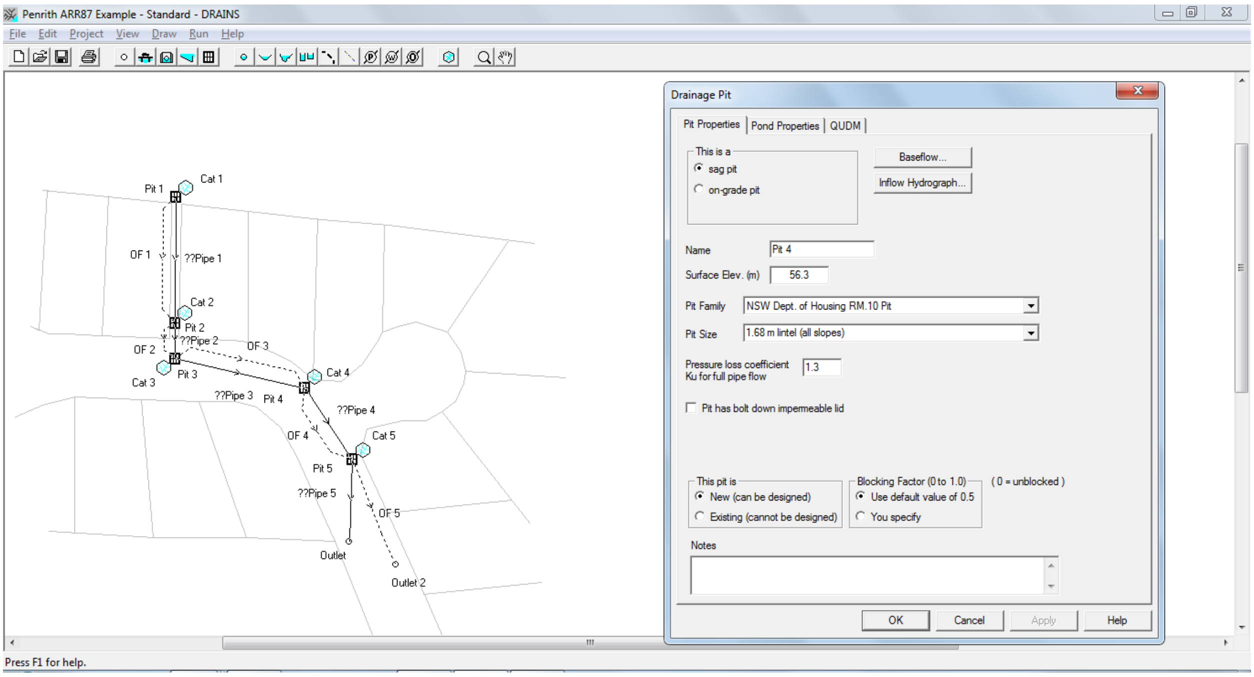


Figure 3.30 Sample System with Initial Pressure Change Coefficients

For example, you might set up a system as shown below, guessing K_u factors, or setting all factors to the default value of 1.5. You would than run the models and select the method you wish to apply, in this case the QUDM Chart procedure, as shown in Figure 3.31.

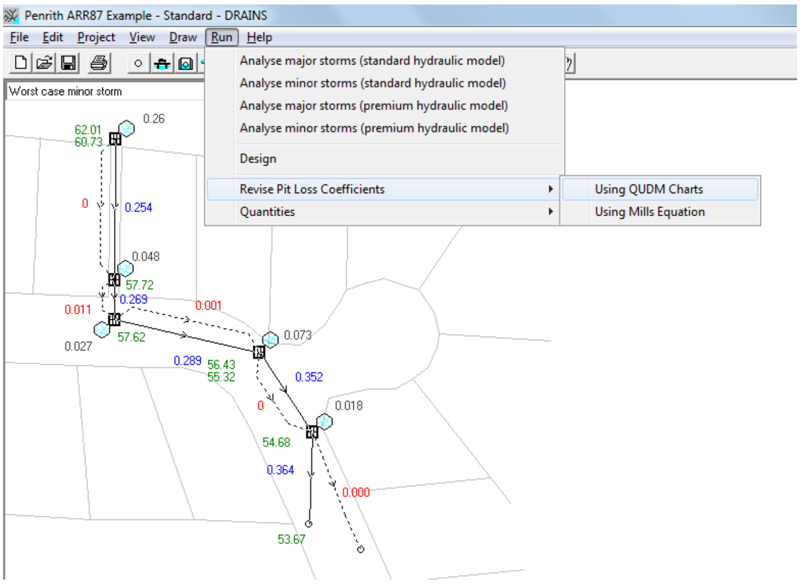
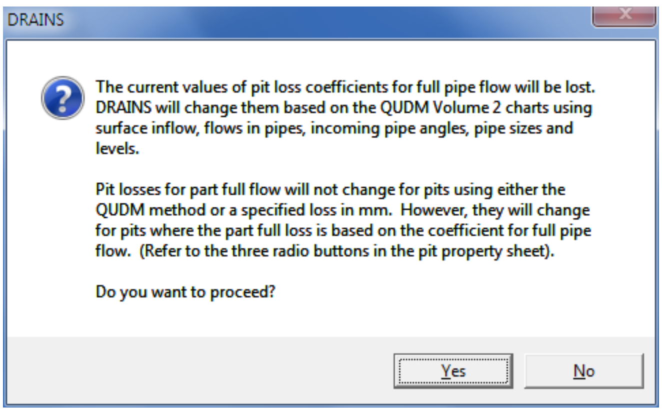
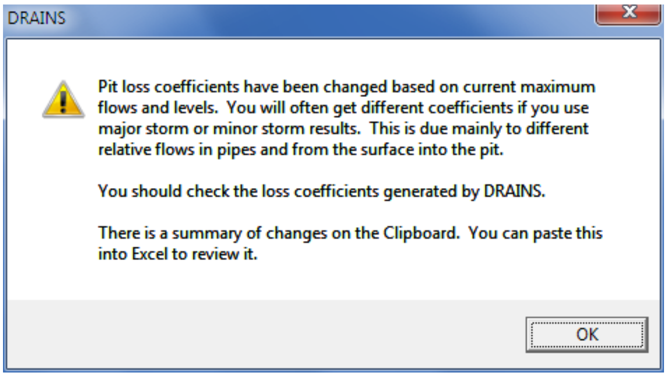


Figure 3.31 Applying the QUDM Charts Procedure

The following messages will appear.





A table of changes can be pasted from the Clipboard to a spreadsheet and displayed:

	A	B	C	D	E
1	Pit	Initial K	Revised K	Chart	Ratios
2	Pit 5	0.83	0.83	A1-9	Du/Do=1.00, Qg/Qo=0.05, S/Do=1.0
3	Pit 4	1.28	1.28	A1-9	Du/Do=1.00, Qg/Qo=0.19, S/Do=1.1
4	Pit 3	1.87	1.87	A1-14	Du/Do=1.00, Qg/Qo=0.12, S/Do=1.1
5	Pit 2	0.72	0.72	A1-5	Du/Do=1.00, Qg/Qo=0.13, S/Do=1.0
6	Pit 1	5.93	5.93	A1-4	H/Do=0.0, Vo2/(2gDo)=0.02

The Chart referred to in Column D is the one selected from those in the Queensland Urban Drainage Manual, and the Ratios are those used to enter the chart to determine the k_u or K values. Further details are given in Section 5.6.6(c).

The model will contain the revised coefficients. The process of running the model and adjusting the coefficients should be repeated once or twice more to allow the procedure to converge to a fixed set of k_u values. Since values depend on flowrates and HGL levels, this process must be run separately for minor and major flows in pipe system design, generating different sets of coefficients.

The procedure for the Mills equation is similar, but simpler. Strictly speaking, both procedures need to be applied iteratively, since changing k_u values will alter flowrates and HGLs, which in turn influence the selection of the k_u values. Two iterations might be usually required when using Mills Method while three or four iterations may be required using the QUDM procedure. As indicated in the second message displayed for the QUDM procedure, the changes made are presented in a spreadsheet placed on the Clipboard, and this can be used to check that convergence has occurred. k_u values created by this method can be manually overwritten.

3.4.5 Quantities

The **Quantities** option in the **Run** menu displays or prints out a table of quantities for the pipes in the current system, as shown in Figure 3.33. This complements the information printed for each completely-defined pipe at the bottom of its property sheet, as shown in .

DRAINS calculates excavation volumes from pipe lengths and invert levels, assuming the trench widths given in Table 3.1 **Table 3.1**, with 200 mm and the diameter being added for each additional parallel pipe. The bedding depth is assumed to be 50 mm below the outside of the pipe wall.

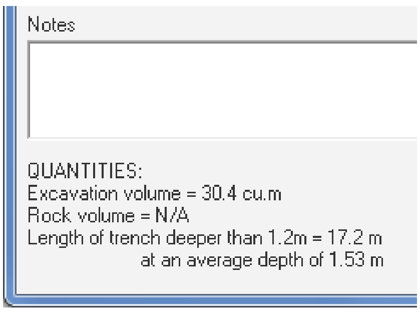
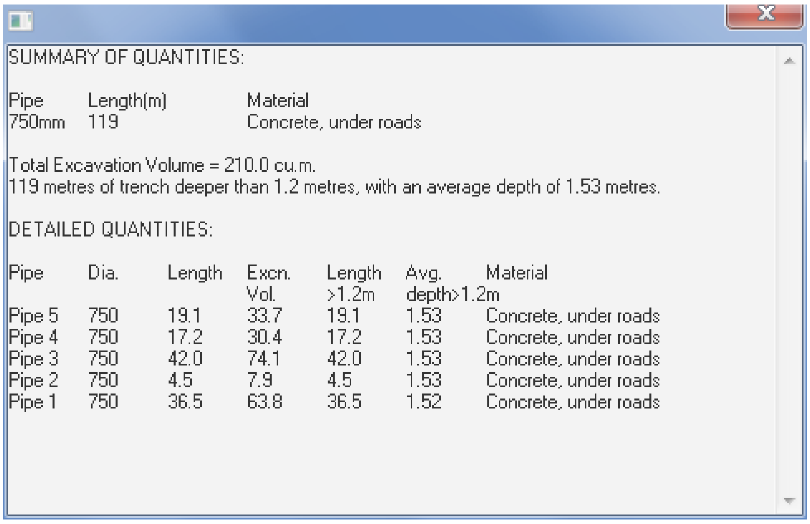


Figure 3.32 Quantities Information in Pipe Property Sheet



SUMMARY OF QUANTITIES:

Pipe	Length(m)	Material
750mm	119	Concrete, under roads

Total Excavation Volume = 210.0 cu.m.
119 metres of trench deeper than 1.2 metres, with an average depth of 1.53 metres.

DETAILED QUANTITIES:

Pipe	Dia.	Length	Excn. Vol.	Length >1.2m	Avg. depth>1.2m	Material
Pipe 5	750	19.1	33.7	19.1	1.53	Concrete, under roads
Pipe 4	750	17.2	30.4	17.2	1.53	Concrete, under roads
Pipe 3	750	42.0	74.1	42.0	1.53	Concrete, under roads
Pipe 2	750	4.5	7.9	4.5	1.53	Concrete, under roads
Pipe 1	750	36.5	63.8	36.5	1.52	Concrete, under roads

Figure 3.33 The Summary of Quantities

Table 3.1 Default Trench Width Table

Nominal Diameter (mm)	**Trench Width** (mm)
300 mm or less	550 mm
301 - 375 mm	650 mm
376 - 450 mm	750 mm
451 - 525 mm	850 mm
526 - 600 mm	950 mm
601 - 675 mm	1050 mm
676 - 750 mm	1150 mm
751 - 900 mm	1400 mm
902 - 1000 mm	1550 mm
1001 - 1200 mm	1800 mm
1201 mm or greater	Diameter + 750 mm

3.5 Output Options

3.5.1 Transfers of Displays and Screen Print-Outs

Section 3.3.2 described the various screen displays that are provided by *DRAINS* prior to run calculations. Additional displays become available once a run is made. These include hydrographs, HGL level plots, tables of flowrates and HGLs.

Data and results can be printed from many of the display windows using the **File** and **Edit** options in their windows, such as the hydrograph display in . These can also be copied to reports and calculation files. You can also use the screen capture techniques available in all Windows applications, such as the **Print Screen** key and **Alt** + **Print Screen** keys, or specialist screen capture programs to produce outputs such as Figure 3.34.

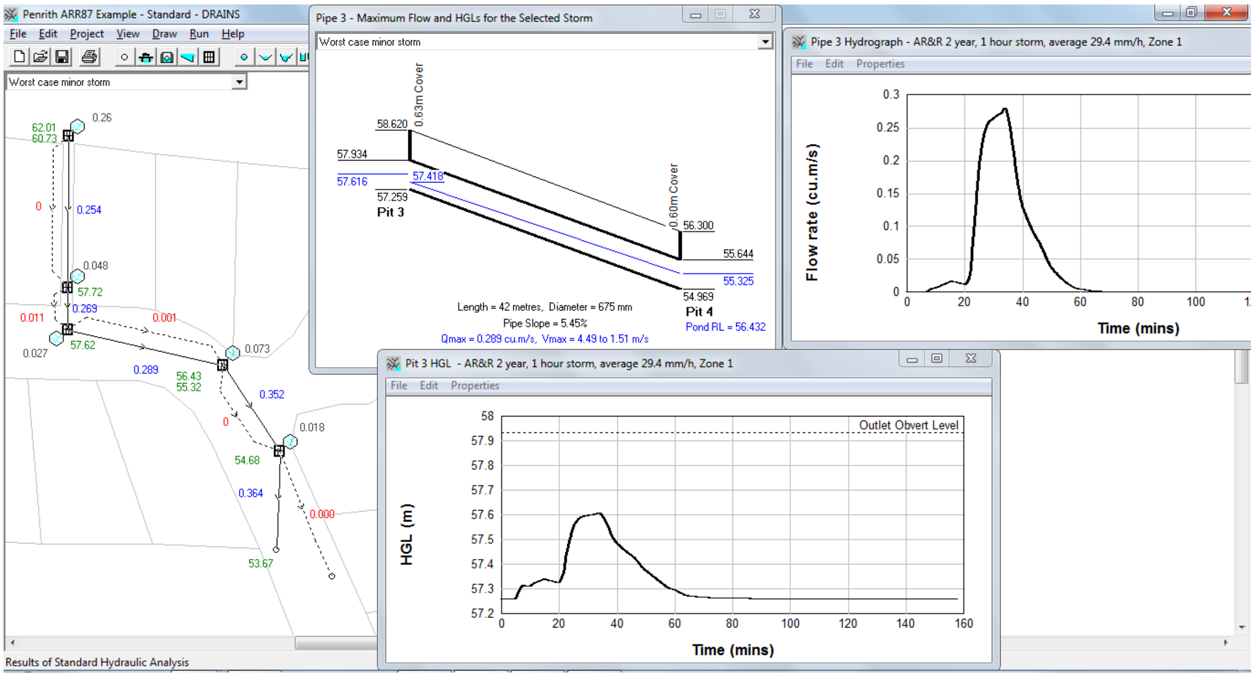


Figure 3.34 DRAINS Results showing Main Window, Hydrograph and HGL Plot Windows

3.5.2 *DRAINS* Print Diagram Option

DRAINS has a facility for printing out the system displayed on a screen, either completely, or as the view shown on the screen. This is implemented in the **Print Diagram** option in the **File** menu, using the dialog box shown in

Figure 3.35. Font sizes can be altered. The **OK** button starts the printout, while the **Setup...** button opens a Printer Setup dialog box.

In the past, this facility has not worked with some printers, due to problems with printer drivers. Trying the options now available should produce a satisfactory image. Another way around printing problems is to print to a **pdf** file, if you have Adobe Acrobat or another program capable of doing this, and then to print from the **pdf** file.

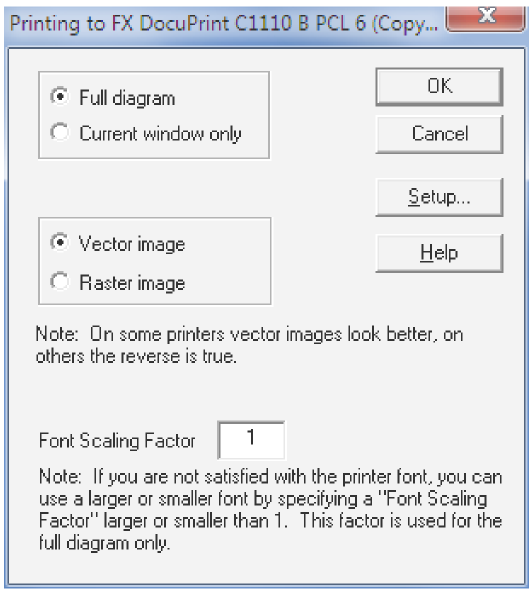


Figure 3.35 Print Diagram Dialog Box

3.5.3 DXF Exports

The process of importing data in DXF format was presented in Section 3.2.2. There are two types of output via DXF file format, one of the most common formats used for drawings. With the **`Toowoomba Estate.drn`** file, you can export a plan view to scale using the **Export DXF File…** option in the **File** menu. This opens a **Save As** dialog box, and after a file name and location are specified, opens the DXF File dialog box shown in

Figure **3.36**. The resulting file can be opened in a drawing program, appearing as shown in Figure 3.37. The background and pipes are supplied on different CAD layers.

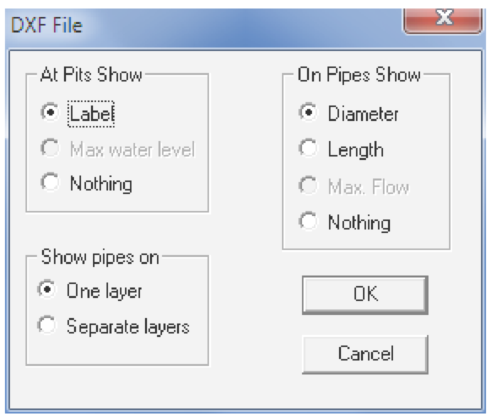


Figure 3.36 DXF File Details Dialog Box

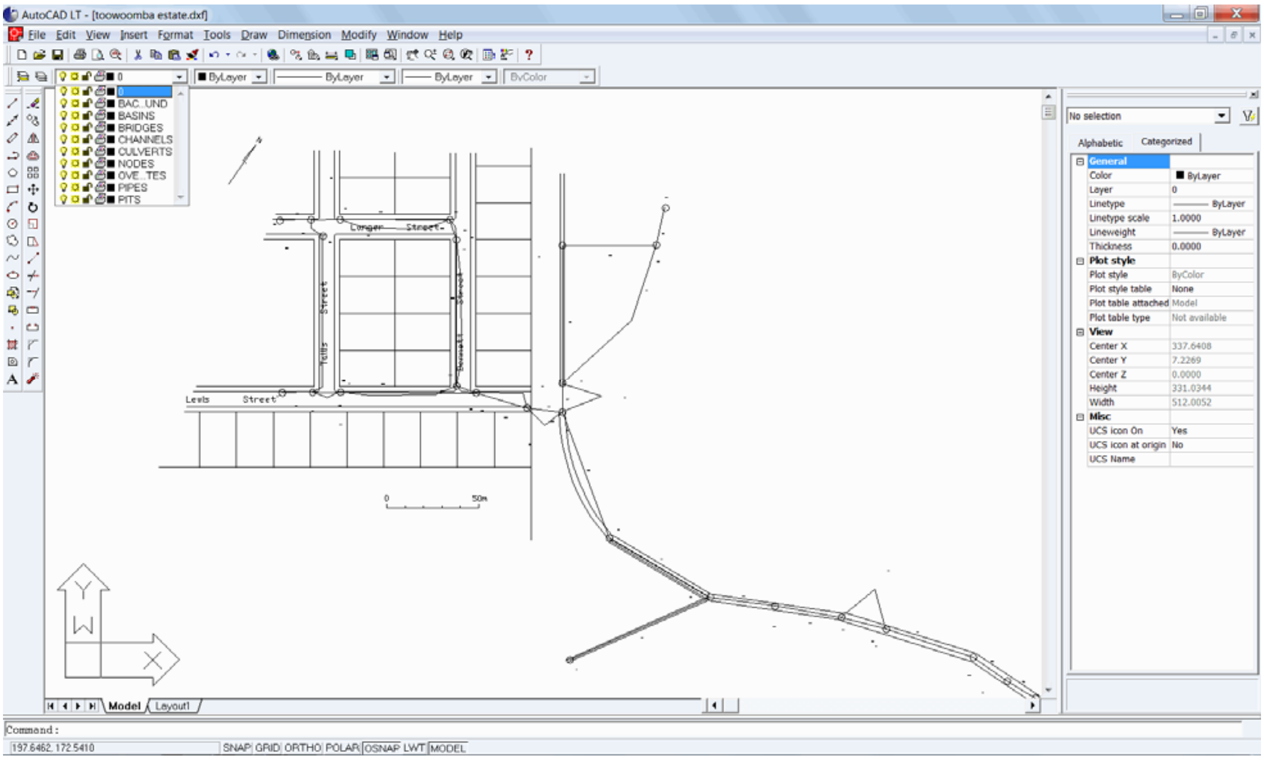


Figure 3.37 Drawing Transferred Out of *DRAINS* in DXF Format

A longitudinal section can be exported by nominating a path between neighbouring pits, and then specifying drawing characteristics. The option **Export ► DXF Long Section…** in the **File** menu opens the dialog boxes shown in Figure 3.38.

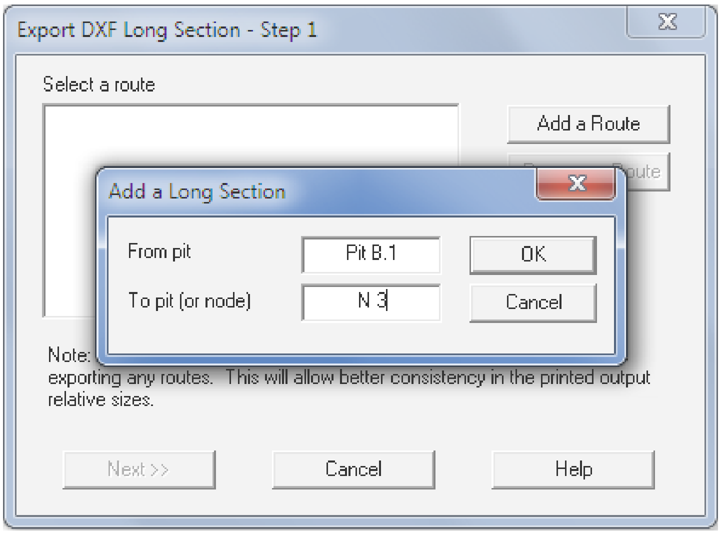


Figure 3.38 Dialog Boxes for setting Paths for Plotting Long Sections

The smaller box is used to define a continuous pipe route. You need to specify the starting and ending node names exactly, allowing for blanks and the case of words.

Once a route is selected and the Next button is clicked, a preview like that shown in Figure 3.39 appears. This is in a window that can be enlarged by clickin on the **Maximize** button (circled) at the top right of the window.

The Customise button opens the dialog box shown in Figure 3.40, which can be used to set drawing features. Changes are reflected in the preview.

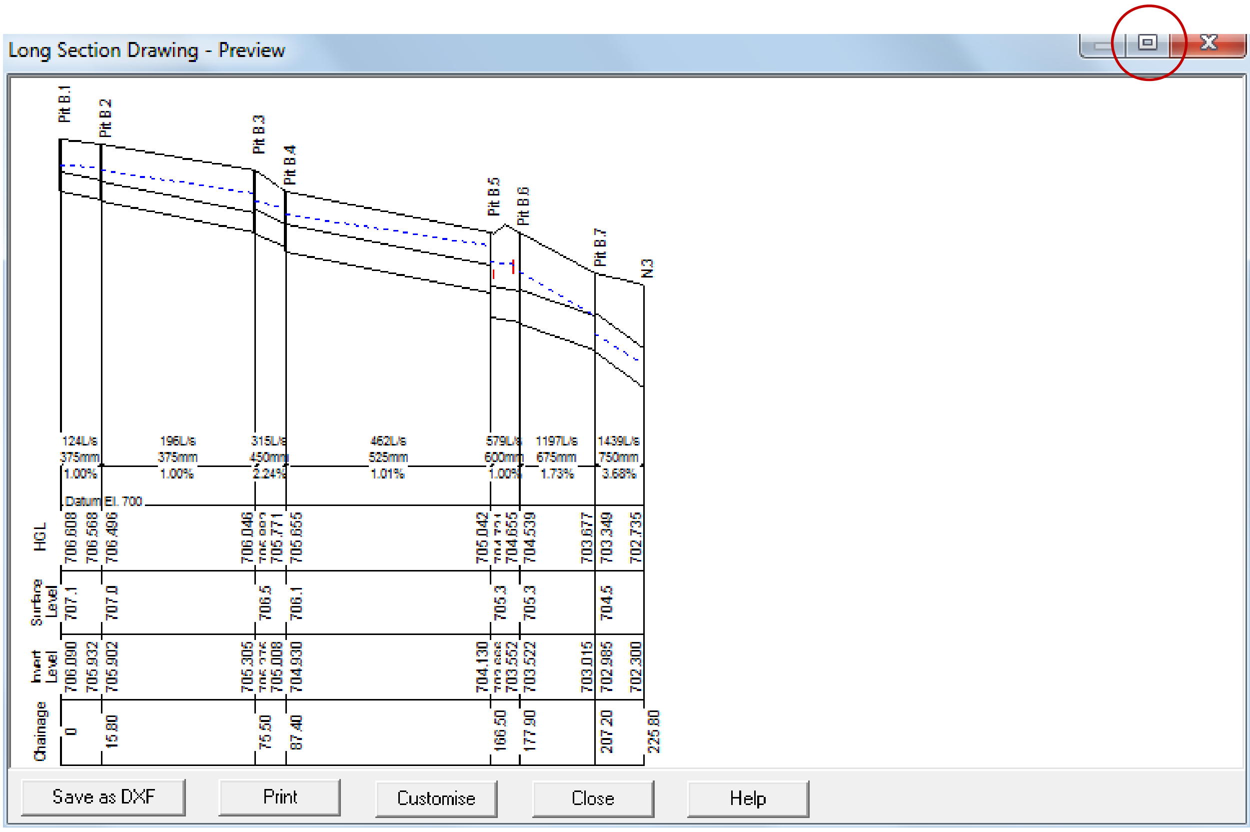


Figure 3.39 Preview of Long Section Plot

Once a satisfactory layout is achieved, clicking the **Save as DXF** button opens a window in which the file name and location can be specified. This creates the DXF file, which can then be viewed and manipulated in a CAD program, as shown in Figure 3.41 and printed from this.

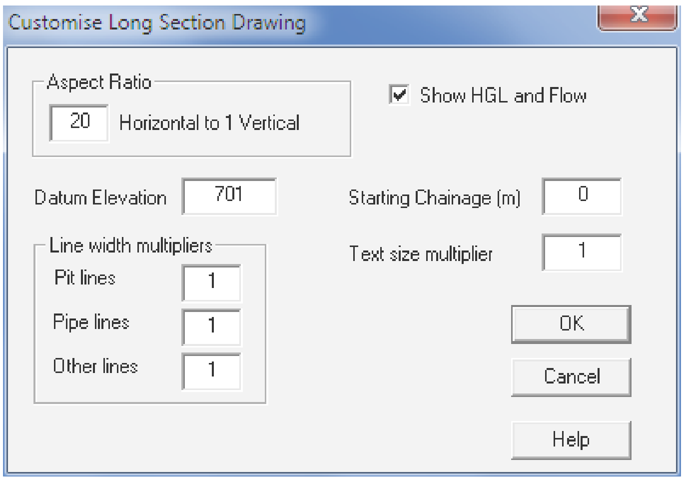


Figure 3.40 Dialog Box for Customising a Long Section

3.5.4 Spreadsheet Outputs (and Inputs)

The spreadsheet option provides a convenient way to view and store data and results, as well as a medium for transferring information between *DRAINS* and other programs. It effectively supersedes the text file output described in the previous section, although this is retained for the convenience of users.

To exchange information with a spreadsheet program, say Excel, both programs must be opened. Information is exchanged via the Windows Clipboard by selecting the copy and paste options in the **Edit** menu. After selecting **Copy Data to Spreadsheet** in *DRAINS*, as shown in Figure 3.42, transfer to Excel and select **Paste** from its **Edit** menu.

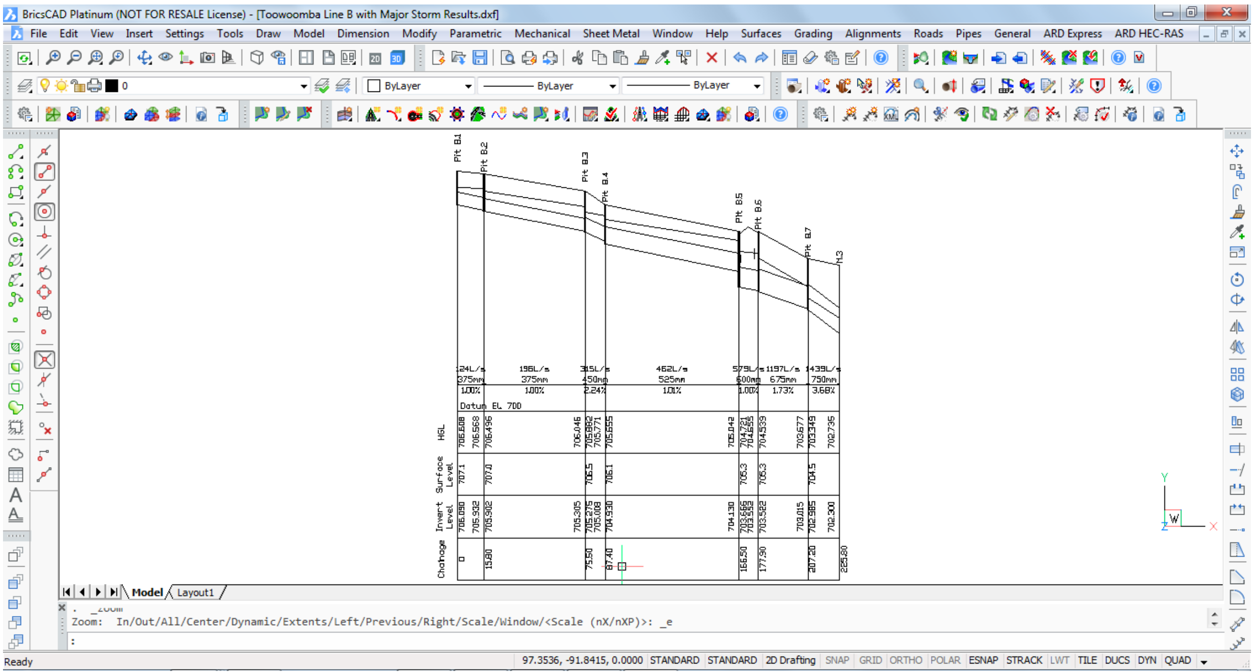


Figure 3.41 The Exported Longitudinal Section, with Hydraulic Grade Line

The information shown in Figure 3.43 appears. Almost all the information entered for components is presented, organised by type of component - PIPE/NODE, SUB-CATCHMENT, etc. This worksheet can be given a name such as 'Data' by double-clicking on the tag at the bottom of the sheet and writing in the name in the space that is highlighted. X-Y coordinates are given for pits and nodes, referring to their positions in the Main Window. If a base drawing is imported from a CAD or GIS file the coordinate system will be consistent with this.

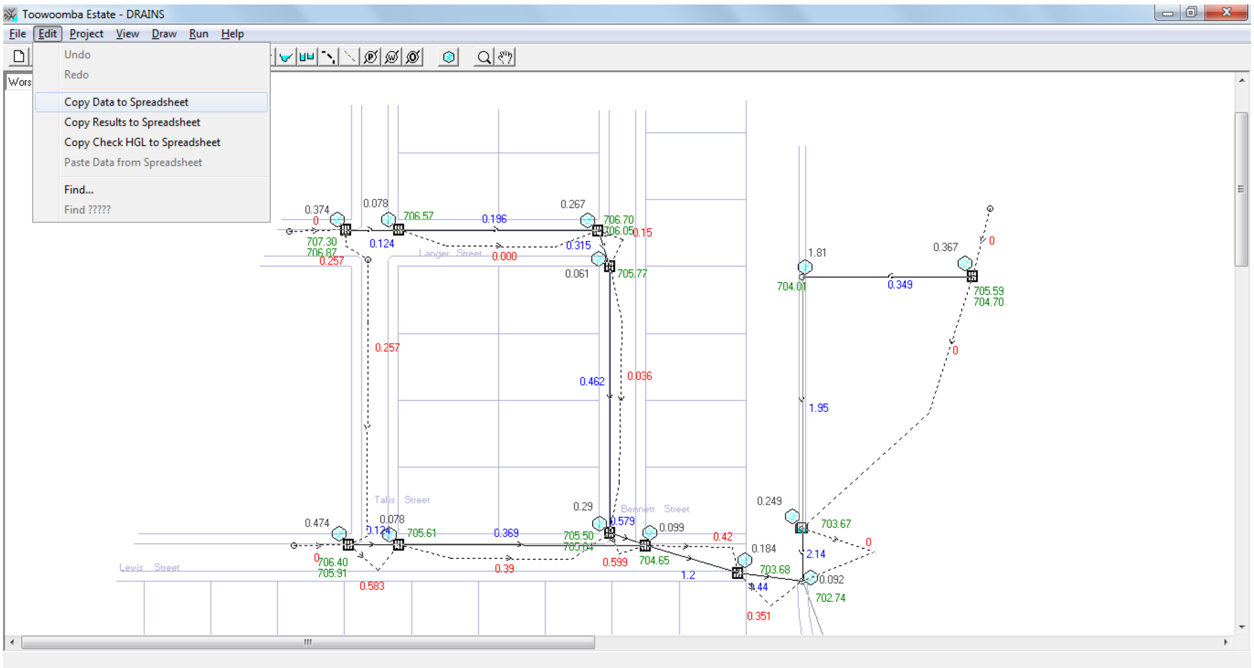
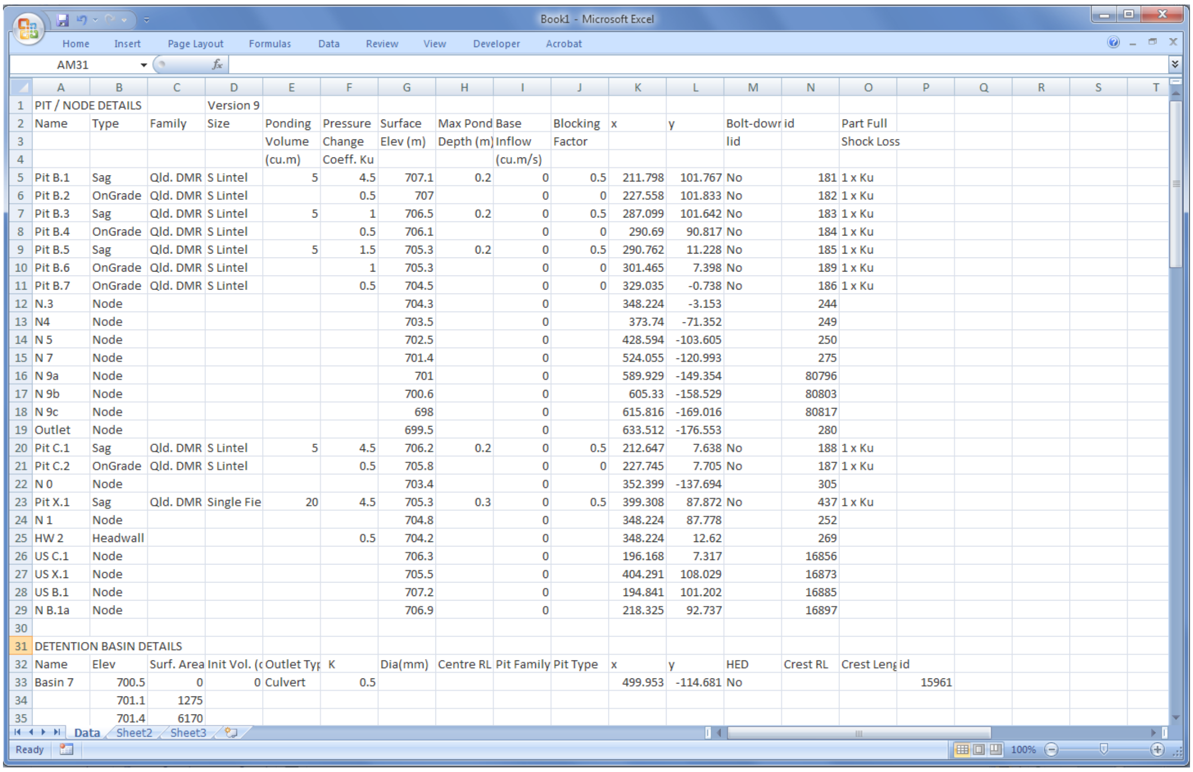


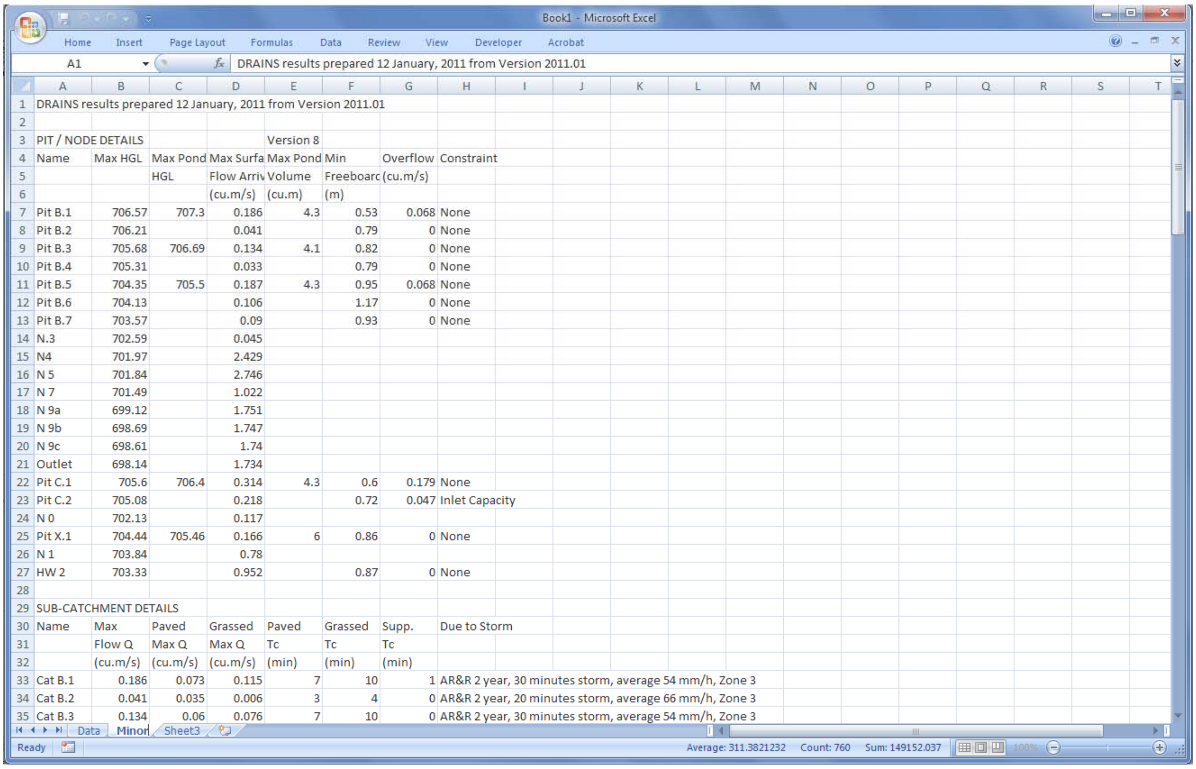
Figure 3.42 Copying Spreadsheet Data to the Clipboard after a Design Run



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	PIT / NODE DETAILS			Version 9												
2	Name	Type	Family	Size	Ponding	Pressure	Surface	Max Pond	Base	Blocking	x	y	Bolt-dowr	id	Part Full	
3					Volume	Change	Elev (m)	Depth (m)	Inflow	Factor			lid		Shock Loss	
4					(cu.m)	Coeff. Ku			(cu.m/s)							
5	Pit B.1	Sag	Qld. DMR	S Lintel	5	4.5	707.1	0.2	0	0.5	211.798	101.767	No	181	1 x Ku	
6	Pit B.2	OnGrade	Qld. DMR	S Lintel		0.5	707		0	0	227.558	101.833	No	182	1 x Ku	
7	Pit B.3	Sag	Qld. DMR	S Lintel	5	1	706.5	0.2	0	0.5	287.099	101.642	No	183	1 x Ku	
8	Pit B.4	OnGrade	Qld. DMR	S Lintel		0.5	706.1		0	0	290.69	90.817	No	184	1 x Ku	
9	Pit B.5	Sag	Qld. DMR	S Lintel	5	1.5	705.3	0.2	0	0.5	290.762	11.228	No	185	1 x Ku	
10	Pit B.6	OnGrade	Qld. DMR	S Lintel		1	705.3		0	0	301.465	7.398	No	189	1 x Ku	
11	Pit B.7	OnGrade	Qld. DMR	S Lintel		0.5	704.5		0	0	329.035	-0.738	No	186	1 x Ku	
12	N.3	Node					704.3		0		348.224	-3.153		244		
13	N4	Node					703.5		0		373.74	-71.352		249		
14	N 5	Node					702.5		0		428.594	-103.605		250		
15	N 7	Node					701.4		0		524.055	-120.993		275		
16	N 9a	Node					701		0		589.929	-149.354		80796		
17	N 9b	Node					700.6		0		605.33	-158.529		80803		
18	N 9c	Node					698		0		615.816	-169.016		80817		
19	Outlet	Node					699.5		0		633.512	-176.553		280		
20	Pit C.1	Sag	Qld. DMR	S Lintel	5	4.5	706.2	0.2	0	0.5	212.647	7.638	No	188	1 x Ku	
21	Pit C.2	OnGrade	Qld. DMR	S Lintel		0.5	705.8		0	0	227.745	7.705	No	187	1 x Ku	
22	N 0	Node					703.4		0		352.399	-137.694		305		
23	Pit X.1	Sag	Qld. DMR	Single Fie	20	4.5	705.3	0.3	0	0.5	399.308	87.872	No	437	1 x Ku	
24	N 1	Node					704.8		0		348.224	87.778		252		
25	HW 2	Headwall				0.5	704.2		0		348.224	12.62		269		
26	US C.1	Node					706.3		0		196.168	7.317		16856		
27	US X.1	Node					705.5		0		404.291	108.029		16873		
28	US B.1	Node					707.2		0		194.841	101.202		16885		
29	N B.1a	Node					706.9		0		218.325	92.737		16897		
30																
31	DETENTION BASIN DETAILS															
32	Name	Elev	Surf. Area	Init Vol. (c	Outlet Typ	K	Dia(mm)	Centre RL	Pit Family	Pit Type	x	y	HED	Crest RL	Crest Leng	id
33	Basin 7	700.5	0	0	Culvert	0.5					499.953	-114.681	No			15961
34		701.1	1275													
35		701.4	6170													

Figure 3.43 Transferred Data

The results from a Design can then be transferred using the **Copy Results to Spreadsheet** option from the **Edit** menu. This can be pasted into a second worksheet with the tag 'Design' or 'Minor', as shown in Figure 3.44.



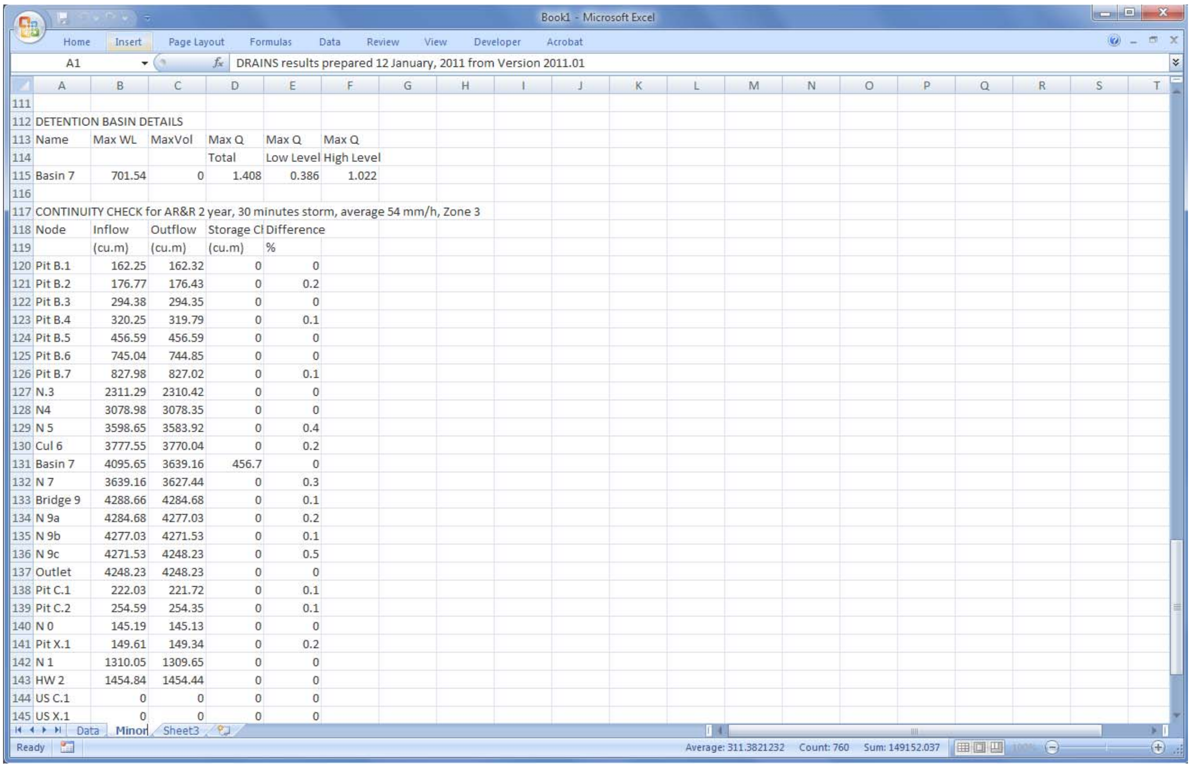
	A	B	C	D	E	F	G	H
1	DRAINS results prepared 12 January, 2011 from Version 2011.01							
2								
3	PIT / NODE DETAILS				Version 8			
4	Name	Max HGL	Max Pond	Max Surfa	Max Pond	Min	Overflow	Constraint
5			HGL	Flow Arriv	Volume	Freeboarc	(cu.m/s)	
6				(cu.m/s)	(cu.m)	(m)		
7	Pit B.1	706.57	707.3	0.186	4.3	0.53	0.068	None
8	Pit B.2	706.21		0.041		0.79	0	None
9	Pit B.3	705.68	706.69	0.134	4.1	0.82	0	None
10	Pit B.4	705.31		0.033		0.79	0	None
11	Pit B.5	704.35	705.5	0.187	4.3	0.95	0.068	None
12	Pit B.6	704.13		0.106		1.17	0	None
13	Pit B.7	703.57		0.09		0.93	0	None
14	N.3	702.59		0.045				
15	N4	701.97		2.429				
16	N 5	701.84		2.746				
17	N 7	701.49		1.022				
18	N 9a	699.12		1.751				
19	N 9b	698.69		1.747				
20	N 9c	698.61		1.74				
21	Outlet	698.14		1.734				
22	Pit C.1	705.6	706.4	0.314	4.3	0.6	0.179	None
23	Pit C.2	705.08		0.218		0.72	0.047	Inlet Capacity
24	N 0	702.13		0.117				
25	Pit X.1	704.44	705.46	0.166	6	0.86	0	None
26	N 1	703.84		0.78				
27	HW 2	703.33		0.952		0.87	0	None
28								
29	SUB-CATCHMENT DETAILS							
30	Name	Max	Paved	Grassed	Paved	Grassed	Supp.	Due to Storm
31		Flow Q	Max Q	Max Q	Tc	Tc	Tc	
32		(cu.m/s)	(cu.m/s)	(cu.m/s)	(min)	(min)	(min)	
33	Cat B.1	0.186	0.073	0.115	7	10	1	AR&R 2 year, 30 minutes storm, average 54 mm/h, Zone 3
34	Cat B.2	0.041	0.035	0.006	3	4	0	AR&R 2 year, 20 minutes storm, average 66 mm/h, Zone 3
35	Cat B.3	0.134	0.06	0.076	7	10	0	AR&R 2 year, 30 minutes storm, average 54 mm/h, Zone 3

Figure 3.44 Transferred Design Results

As with the data, results are organised by the type of component, in the same order. Calculated flowrates, times, velocities and other information are presented. Where multiple rainfall patterns are specified, the information presented is for the worst-case result - the greatest flowrate, highest HGL level, etc. among the results for the various storms.

The particular storm that causes this worst condition is noted in the last column for each component. (*DRAINS* does not transfer the specific results for each individual storm. If you wish to do this, you should use the **Select Storms** option in the **Project** menu to run *DRAINS* with single storms and transfer the results one at a time.) The velocities shown correspond to the peak flowrates and may be part-full or full pipe velocities, depending on the conditions when the maximum flowrate occurred.

A continuity check of inflow and outflow hydrograph volumes at each node (presented at the bottom of the spreadsheet shown in Figure 3.45) applies for the most severe storm. It shows up differences in continuity, due to factors such as the absence of an overflow route when overflows occur. However, it does not show any discontinuity due to the introduction of a baseflow or a user-provided inflow hydrograph. Where there is a lack of continuity at a node, the cause can be explored by examining the inputs and outputs to the relevant node using the **View Hydrographs** and **View Hydrographs as Tables** options in the pop-up menus for pipes, channels, overflow routes and sub-catchments. The run log that appeared after the run completed is also presented at the end of the Results output.



	A	B	C	D	E	F
111						
112	DETENTION BASIN DETAILS					
113	Name	Max WL	MaxVol	Max Q	Max Q	Max Q
114				Total	Low Level	High Level
115	Basin 7	701.54	0	1.408	0.386	1.022
116						
117	CONTINUITY CHECK for AR&R 2 year, 30 minutes storm, average 54 mm/h, Zone 3					
118	Node	Inflow	Outflow	Storage Cl	Difference	
119		(cu.m)	(cu.m)	(cu.m)	%	
120	Pit B.1	162.25	162.32	0	0	
121	Pit B.2	176.77	176.43	0	0.2	
122	Pit B.3	294.38	294.35	0	0	
123	Pit B.4	320.25	319.79	0	0.1	
124	Pit B.5	456.59	456.59	0	0	
125	Pit B.6	745.04	744.85	0	0	
126	Pit B.7	827.98	827.02	0	0.1	
127	N.3	2311.29	2310.42	0	0	
128	N4	3078.98	3078.35	0	0	
129	N 5	3598.65	3583.92	0	0.4	
130	Cul 6	3777.55	3770.04	0	0.2	
131	Basin 7	4095.65	3639.16	456.7	0	
132	N 7	3639.16	3627.44	0	0.3	
133	Bridge 9	4288.66	4284.68	0	0.1	
134	N 9a	4284.68	4277.03	0	0.2	
135	N 9b	4277.03	4271.53	0	0.1	
136	N 9c	4271.53	4248.23	0	0.5	
137	Outlet	4248.23	4248.23	0	0	
138	Pit C.1	222.03	221.72	0	0.1	
139	Pit C.2	254.59	254.35	0	0.1	
140	N 0	145.19	145.13	0	0	
141	Pit X.1	149.61	149.34	0	0.2	
142	N 1	1310.05	1309.65	0	0	
143	HW 2	1454.84	1454.44	0	0	
144	US C.1	0	0	0	0	
145	US X.1	0	0	0	0	

Figure 3.45 Continuity Checks

When a Design run is followed up by an Analysis run, the results can also be transferred, being pasted in the 'Major' worksheet shown in Figure 3.45. These spreadsheets can be saved and used to document a design or analysis. They can also be transferred from the spreadsheet program to a word processor for inclusion in a report.

In connection with rational method calculations, *DRAINS* has the option **Edit → Copy Check HGL to Spreadsheet** that presents results of a simplified analysis of the drainage system, using assumptions similar to those in the manual analysis procedures set out in Chapter 14 of *Australian Rainfall and Runoff*, 1987 and Chapter 5 of the *Queensland Urban Drainage Manual*. These results are not available for other hydrological models such as the ILSAX and extended rational method models.

For the rational method example shown in Figure 3.46, we can determine pit pressure change coefficients using the method from the outlined in Section 3.4.4 and run this model for minor and major storms. We can then transfer the results of the simplified analysis to Excel in the form shown in

Figure 3.47. Overflow routes from nodes have been provided at the tops of lines. By specifying percentages of downstream sub-catchments contributing, it is possible to define the hydraulic

characteristics of approach flows in the spreadsheet output (see Columns L to O of the Excel worksheet in

Figure 3.47).

This feature has been provided to assist persons documenting or checking designs. It is more conservative than the *DRAINS* calculation procedures, and will specify higher HGLs that might sometimes exceed the freeboard limits at pits. It should therefore be considered as a guide or 'sanity check' rather than as a true representation of the peak HGL levels. Among the reasons for conservatism are that peak flowrates in all pipes are assumed to occur simultaneously.

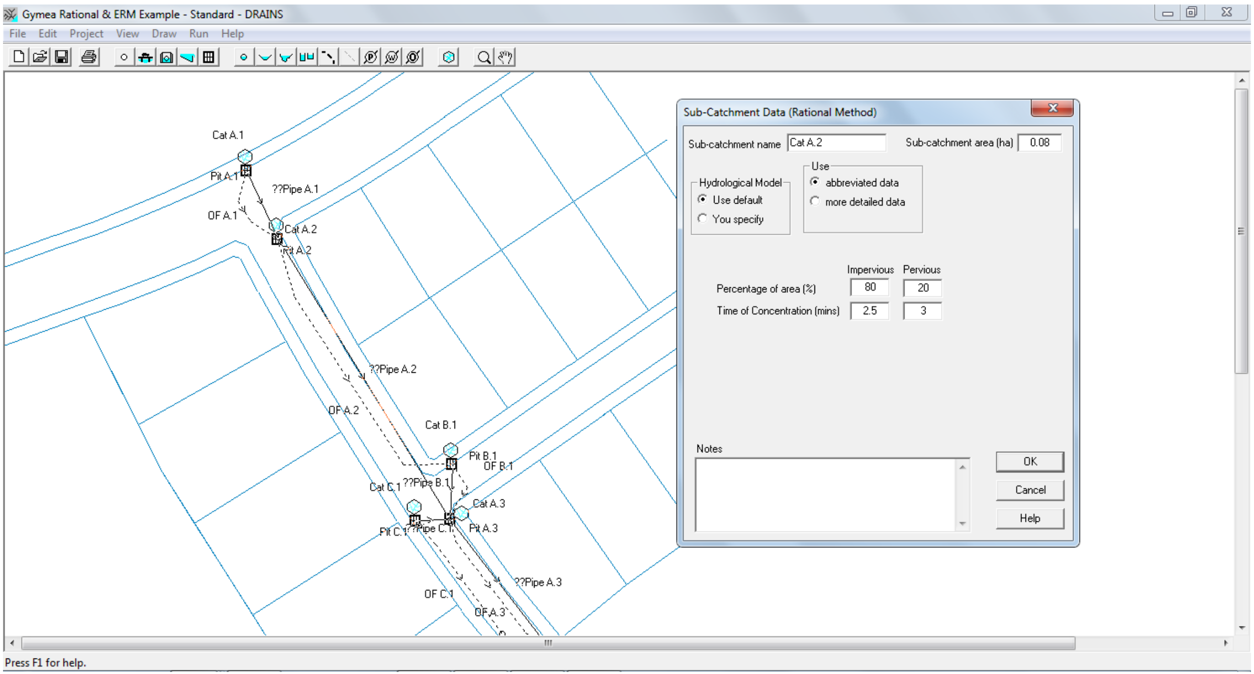
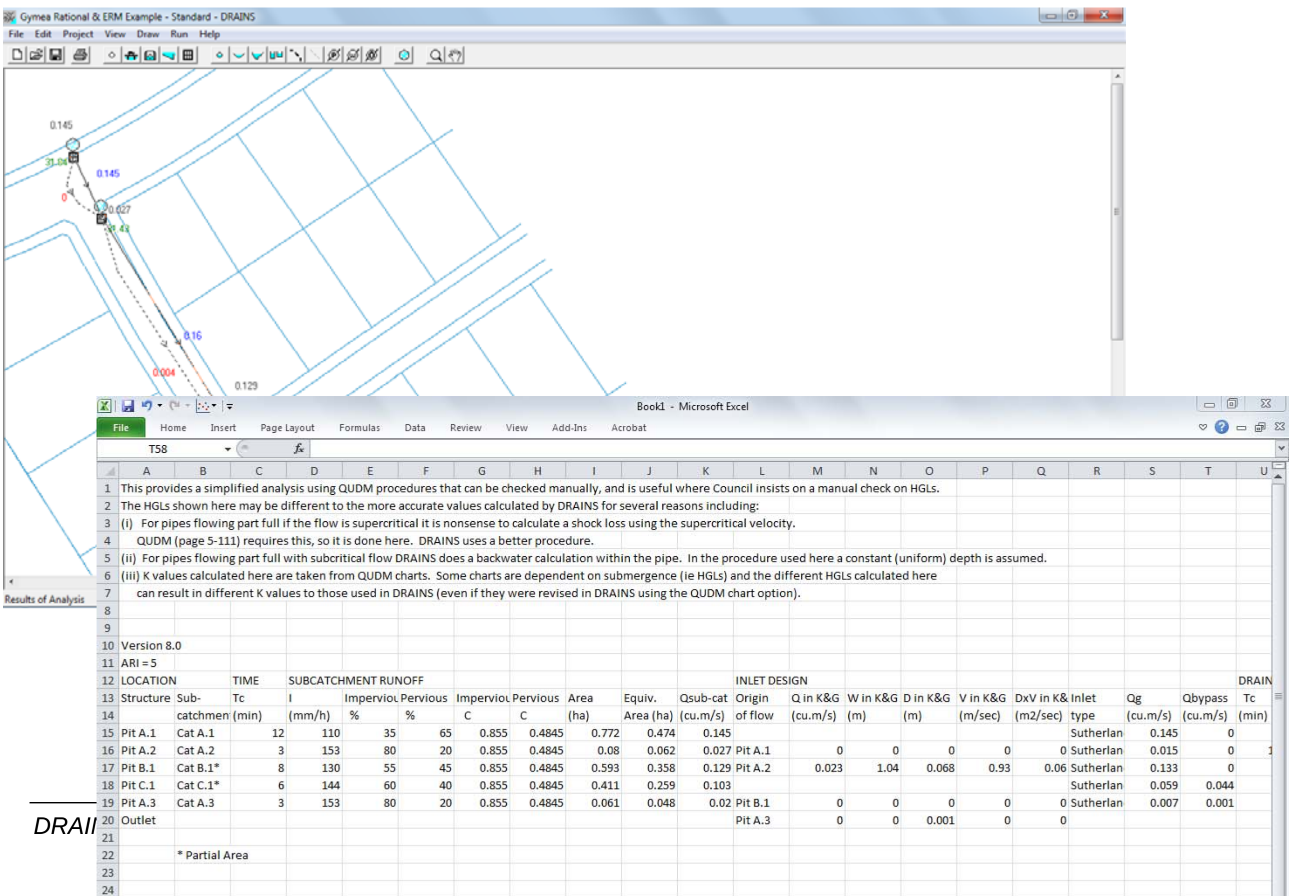


Figure 3.46 Rational Method Example



This provides a simplified analysis using QUDM procedures that can be checked manually, and is useful where Council insists on a manual check on HGLs.
The HGLs shown here may be different to the more accurate values calculated by DRAINS for several reasons including:
(i) For pipes flowing part full if the flow is supercritical it is nonsense to calculate a shock loss using the supercritical velocity.
QUDM (page 5-111) requires this, so it is done here. DRAINS uses a better procedure.
(ii) For pipes flowing part full with subcritical flow DRAINS does a backwater calculation within the pipe. In the procedure used here a constant (uniform) depth is assumed.
(iii) K values calculated here are taken from QUDM charts. Some charts are dependent on submergence (ie HGLs) and the different HGLs calculated here
can result in different K values to those used in DRAINS (even if they were revised in DRAINS using the QUDM chart option).

Version 8.0
ARI = 5

LOCATION		TIME	SUBCATCHMENT RUNOFF								INLET DESIGN									DRAIN
Structure	Sub-catchmen	Tc (min)	I (mm/h)	Imperviou %	Pervious %	Imperviou C	Pervious C	Area (ha)	Equiv. Area (ha)	Qsub-cat (cu.m/s)	Origin of flow	Q in K&G (cu.m/s)	W in K&G (m)	D in K&G (m)	V in K&G (m/sec)	DxV in K& (m2/sec)	Inlet type	Qg (cu.m/s)	Qbypass (cu.m/s)	Tc (min)
Pit A.1	Cat A.1	12	110	35	65	0.855	0.4845	0.772	0.474	0.145							Sutherlan	0.145	0	
Pit A.2	Cat A.2	3	153	80	20	0.855	0.4845	0.08	0.062	0.027	Pit A.1	0	0	0	0	0	Sutherlan	0.015	0	1
Pit B.1	Cat B.1*	8	130	55	45	0.855	0.4845	0.593	0.358	0.129	Pit A.2	0.023	1.04	0.068	0.93	0.06	Sutherlan	0.133	0	
Pit C.1	Cat C.1*	6	144	60	40	0.855	0.4845	0.411	0.259	0.103							Sutherlan	0.059	0.044	
Pit A.3	Cat A.3	3	153	80	20	0.855	0.4845	0.061	0.048	0.02	Pit B.1	0	0	0	0	0	Sutherlan	0.007	0.001	
Outlet											Pit A.3	0	0	0.001	0	0				

* Partial Area

Figure 3.47 Transferred Check HGL Results

Queensland users will be able to convert the *DRAINS* Check HGL outputs to forms set out in QUDM and manuals from Brisbane City Council and Pine Rivers Shire Council, using a ‘DRAINS Rational Method Output Converter’ spreadsheet available from www.watercom.com.au. An output from this is shown in Figure 3.48.

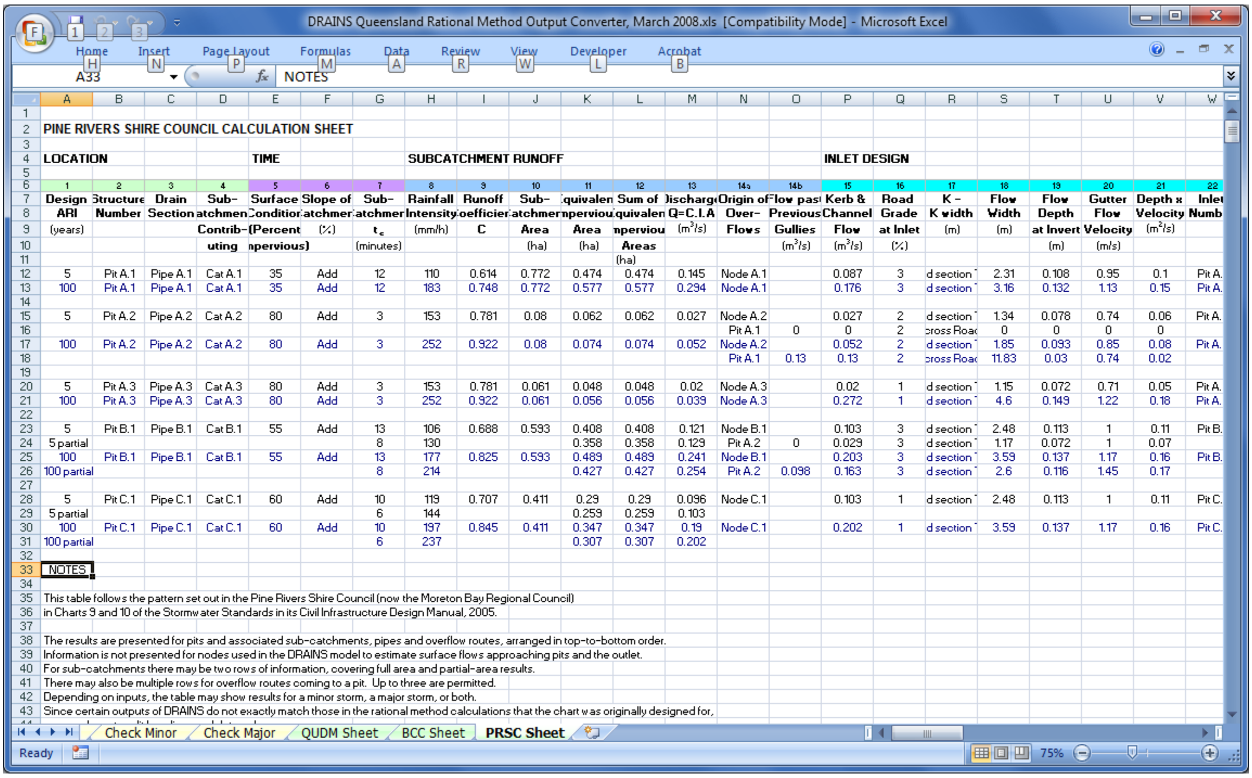


Figure 3.48 Rational Method Converter Results

Data for pipes, pits, nodes and sub-catchments can be transferred back into *DRAINS* using the **Paste Data from Spreadsheet** option in the **Edit** menu. You must first make the required changes and then copy the entire spreadsheet to the Clipboard using the **Copy** option in the spreadsheet. (A quick way of selecting an entire Excel spreadsheet is to click the cell top-left cell between the '1' and 'A' cells.) The changes can then be pasted into *DRAINS* using the **Paste Data from Spreadsheet** option in the **Edit** menu. Because the transfers are made via the Clipboard, it is not necessary to have any direct connection between the spreadsheet file and the *DRAINS* file.

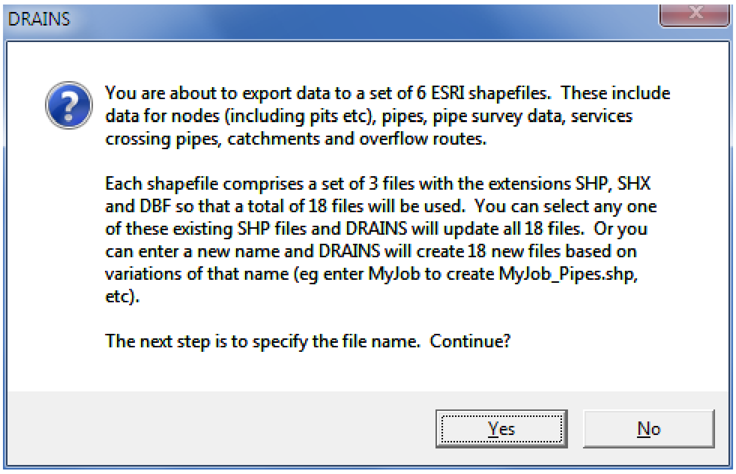
A similar output spreadsheet using ILSAX hydrology can be obtained from Geoffrey O’Loughlin at geoff.oloughlin@tpg.com.au.

3.5.5 GIS File Exports

(a) ***Exporting ESRI (ArcView, ArcInfo, ArcMap) Files***

It is first necessary to establish a system that is capable of being run, such as the example shown in Figure 3.49.

Selecting the **ESRI Shapefiles**… option from the **File -> Export** menu presents the message shown to the right:



If you continue, you will then need to nominate a filename for shapefiles in the dialog box shown in Figure 3.50. You can see from the existing files in this example how six ESRI SHP files are established. Another 12 SHX and DBF files will also be produced.

After a name is entered, the process is complete if there are no results. If results are available, the dialog box shown in Figure 3.51 appears. A suitable name should be added describing the results; here they are for a 2 year average recurrence interval storm. The limited size is due to restrictions on the size of column headings in the database files used in ArcMap. After this is entered, the process is finished.

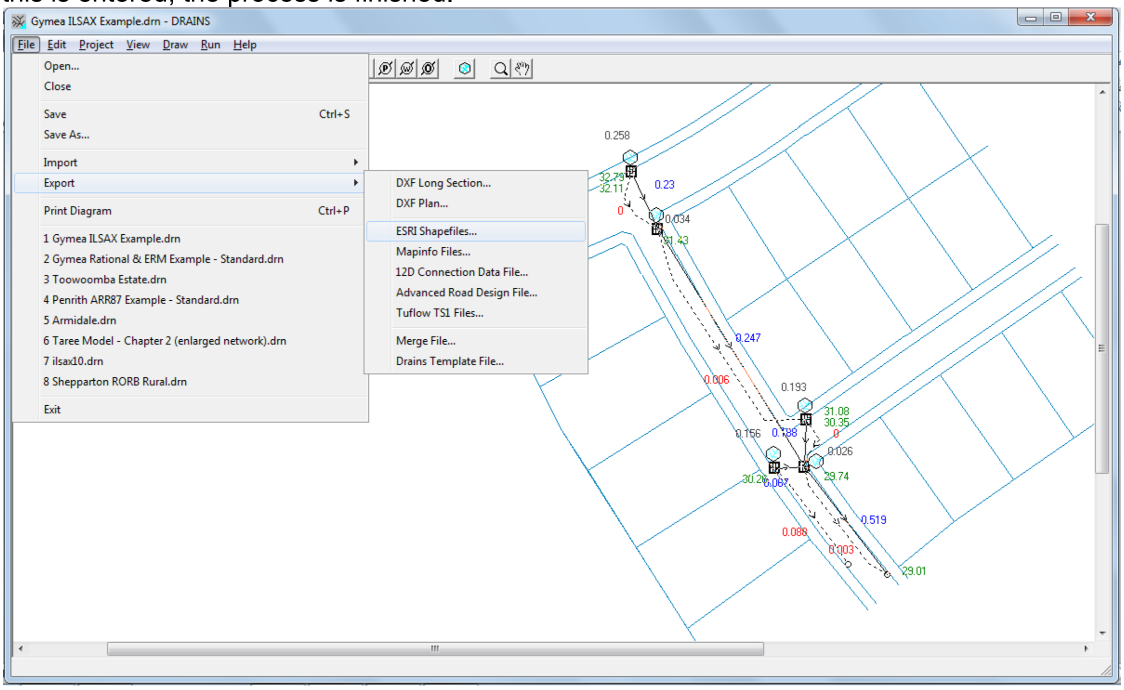


Figure 3.49 System to be Exported to GIS

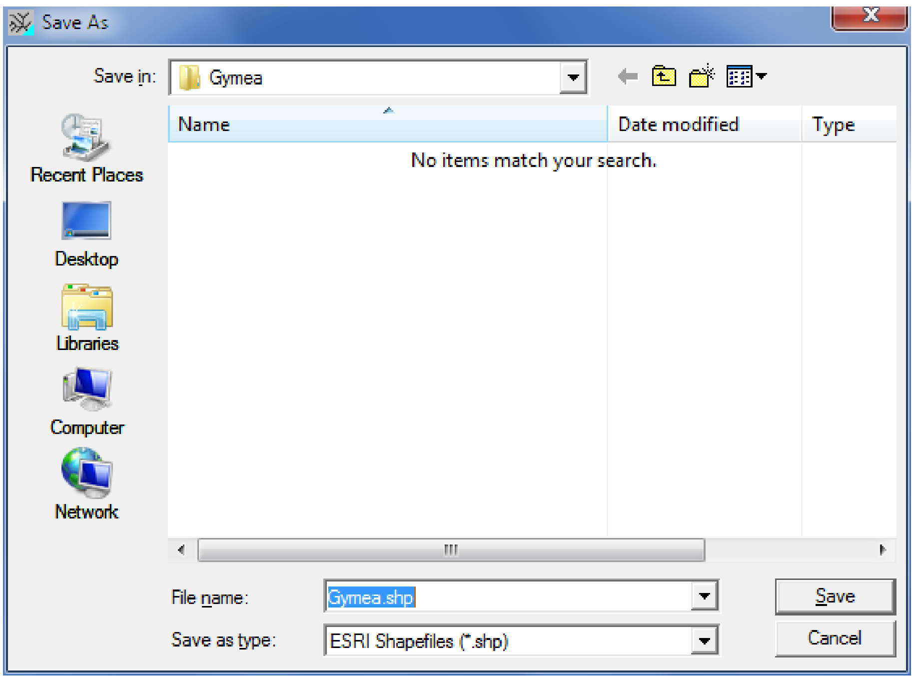


Figure 3.50 Nomination of Shapefile Name

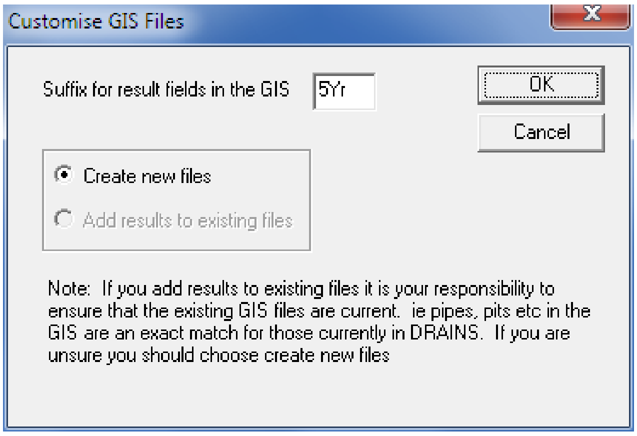


Figure 3.51 Naming of Set of Results

If a background is present in the *DRAINS* model, this will be transferred with the ESRI files. The transferred files can now be viewed in ArcMap as shown in Figure 3.52.

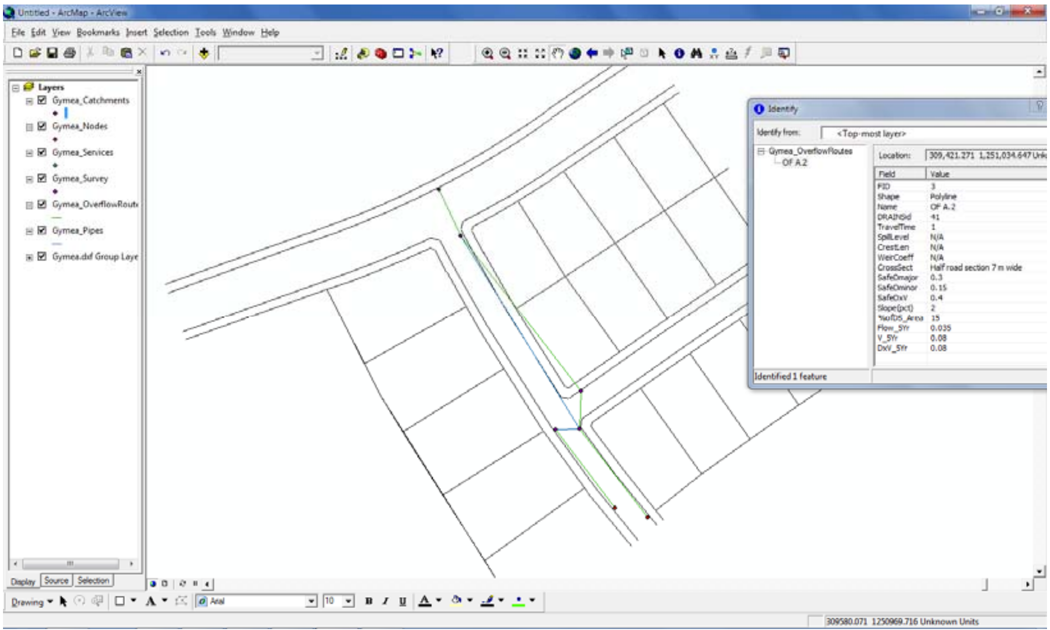
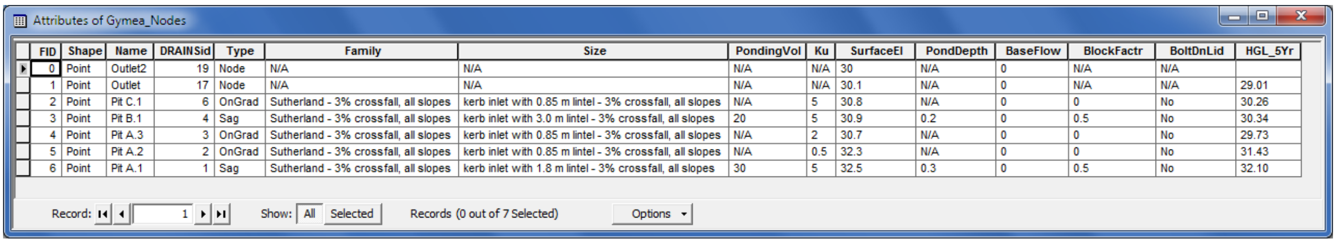


Figure 3.52 Display of Results in ArcMap

A database table is associated with each theme, as shown in Figure 3.53. Note that most values are specified as strings of characters, and must be converted to numerical values using procedures within ESRI programs if these are required to provide thematic displays where colours, line thicknesses or other attributes indicate properties.



Attributes of Gymea_Nodes

FID	Shape	Name	DRAINSid	Type	Family	Size	PondingVol	Ku	SurfaceEl	PondDepth	BaseFlow	BlockFactr	BoltDnLid	HGL_5Yr
0	Point	Outlet2	19	Node	N/A	N/A	N/A	N/A	30	N/A	0	N/A	N/A	
1	Point	Outlet	17	Node	N/A	N/A	N/A	N/A	30.1	N/A	0	N/A	N/A	29.01
2	Point	Pit C.1	6	OnGrad	Sutherland - 3% crossfall, all slopes	kerb inlet with 0.85 m lintel - 3% crossfall, all slopes	N/A	5	30.8	N/A	0	0	No	30.26
3	Point	Pit B.1	4	Sag	Sutherland - 3% crossfall, all slopes	kerb inlet with 3.0 m lintel - 3% crossfall, all slopes	20	5	30.9	0.2	0	0.5	No	30.34
4	Point	Pit A.3	3	OnGrad	Sutherland - 3% crossfall, all slopes	kerb inlet with 0.85 m lintel - 3% crossfall, all slopes	N/A	2	30.7	N/A	0	0	No	29.73
5	Point	Pit A.2	2	OnGrad	Sutherland - 3% crossfall, all slopes	kerb inlet with 0.85 m lintel - 3% crossfall, all slopes	N/A	0.5	32.3	N/A	0	0	No	31.43
6	Point	Pit A.1	1	Sag	Sutherland - 3% crossfall, all slopes	kerb inlet with 1.8 m lintel - 3% crossfall, all slopes	30	5	32.5	0.3	0	0.5	No	32.10

Record: 1 Show: All Selected Records (0 out of 7 Selected) Options

Figure 3.53 Table of Pit Data

Note that this includes results with the '2Yr' added to headings as a suffix. If another run is made and the process is repeated with one of the existing shapefiles nominated in the Save As dialog box, additional

results will be appended, as shown in Figure 3.54 and Figure 3.55, where 100 year ARI results are added to the 5 year ARI results.

If data from a GIS data base can be assembled into this same format, less the results, the **File ► Import** option ESRI **Shapefiles…** can be used to import data into *DRAINS*.

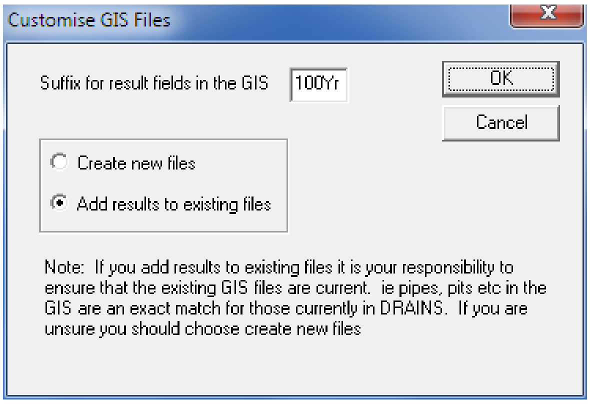
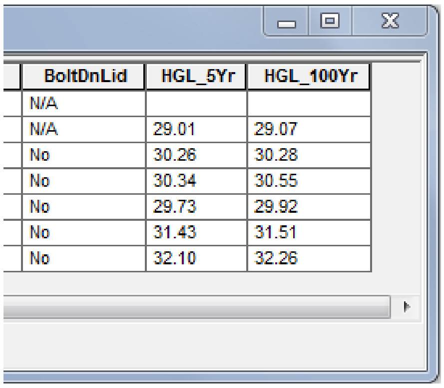


Figure 3.54 Naming of Second Set of Results



BoltDnLid	HGL_5Yr	HGL_100Yr
N/A		
N/A	29.01	29.07
No	30.26	30.28
No	30.34	30.55
No	29.73	29.92
No	31.43	31.51
No	32.10	32.26

Figure 3.55 Expanded Table of Pipe Data

(b) Exporting MapInfo Files

It is first necessary to establish a system that is capable of being run in *DRAINS*, such as the demonstration example shown in Figure 3.49. Selecting the **MapInfo files…** option from the **File -> Export** menu presents the message in Figure 3.56. If you continue, you will then need to nominate a filename for MID/MIF files in the dialog box shown in Figure 3.57.

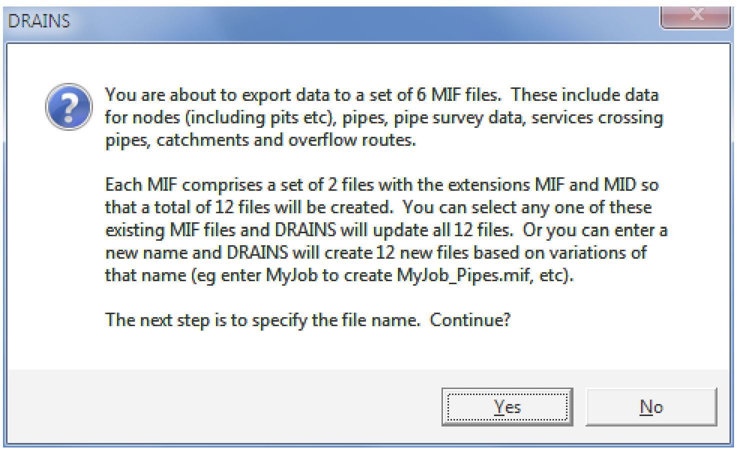


Figure 3.56 Message in MapInfo File Export Procedure

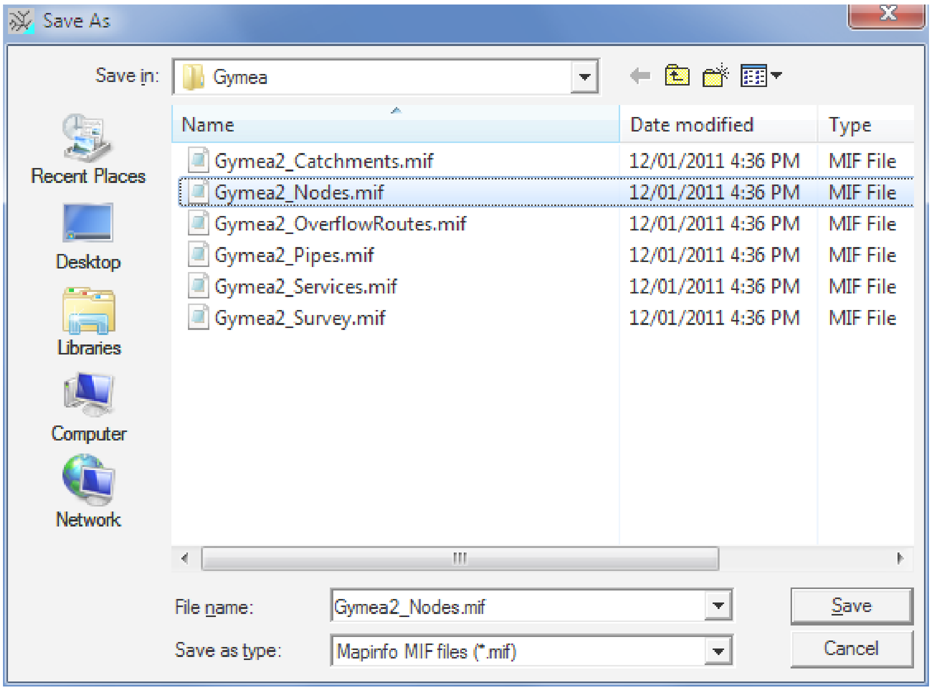


Figure 3.57 Nomination of MID/MIF File Name

You can see from the existing files in this example how six MapInfo MIF files are established. Another six MID files are also produced. After a name is entered, it will be necessary to nominate the projection to be used if the data has not been brought in from MapInfo files. This can be done in the dialog box shown in Figure 3.58 that appears. This has a similar format to the equivalent window in MapInfo.

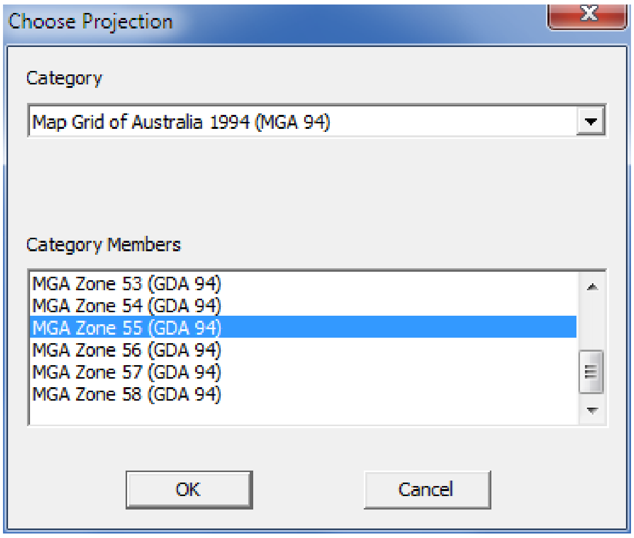


Figure 3.58 Nomination of Projection

The process is then complete if there are no results. If results are available, a dialog box similar to that shown in Figure 3.51 appears. A suitable name should be added describing the results; such as '10Yr' for a 10 year average recurrence interval storm.

A background in the *DRAINS* model will be transferred with the MapInfo files. If there are any problems with the projections, these can be overcome by editing the ASCII MIF file, inserting a line giving the appropriate projection. The transferred files can now be viewed in MapInfo, as shown in Figure 3.59.

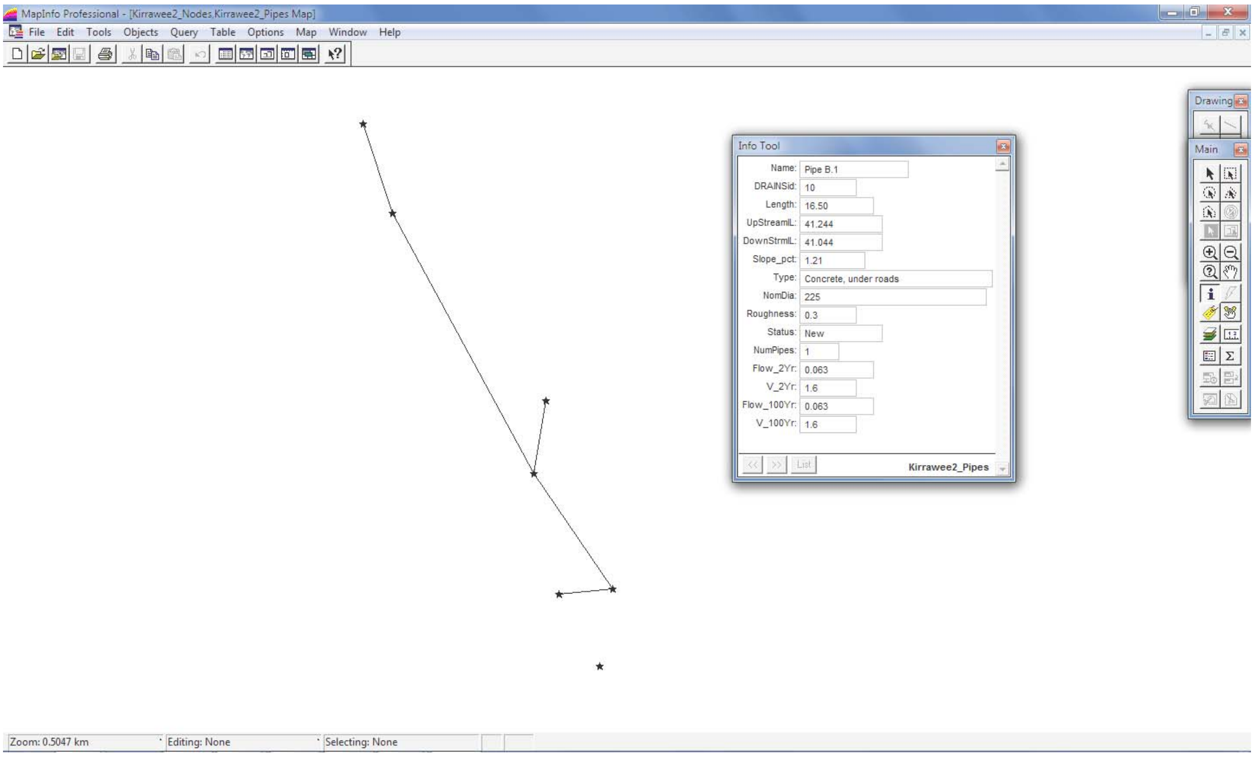
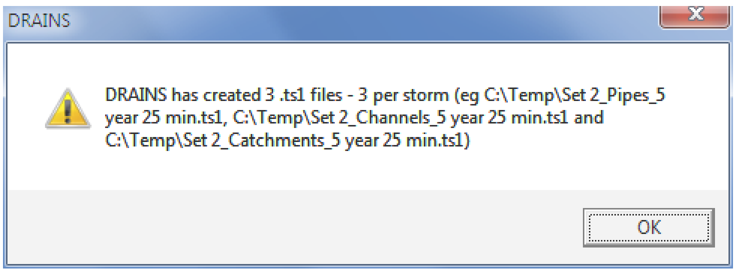


Figure 3.59 Display of Data transferred to MapInfo

'2Yr' and '100Yr' are added to headings as a suffix. If another run is made and the process is repeated with one of the existing shapefiles nominated in the **Save As** dialog box, additional results will be appended.

3.5.6 Hydrograph Outputs in TUFLOW Format

Using the **File → Export → Tuflow TS1 Files…** option, you can export hydrographs in a format used by the 2-dimensional TUFLOW hydraulics program (BMT WBM, 2010). Hydrographs are produced for sub-catchments, pipes and overflow routes for all storm runs made prior to exporting. This format can be read by spreadsheets and editors, and can be used by other programs than TUFLOW. When a transfer is made, the message to the right appears:



3.5.7 Outputs to Linked Applications

As part of the dedicated links from Autodesk Land Desktop, Advanced Road Design and 12d to *DRAINS*, results are transferred back to these applications via database files and the spreadsheet outputs, as described in Section 0 and Section 3.2.7.

3.5.8 Merge Outputs (and Inputs)

The merge options allow you to add *DRAINS* systems together. It is first necessary to export a system as a merge file, before importing it into another system. The two systems are linked the pits at each end of a common pipe, which is the lowest pipe in the system to be added. The procedure is as follows:

(a) Edit the files so that both include two adjacent pits with the same names. Make sure that you have zoomed in to the model so that there is an observable distance between pits. (If the model is at a low magnification, so that individual pipes cannot be seen, there may be round-off errors in the process that *DRAINS* applies when creating a merge file. This may lead to sub-catchments and other components being connected wrongly.)

(b) In the file to be added, use the **Export a Merge File**... option in the **File** menu to create and name a **`.mrg`** merge file.

(c) Then close the file to be added, and open the file with the receiving system. Using the **Import a Merge File…** option in the **File** menu, read in the **.mrg** merge file created in Step (b).

(d) The merged system will appear. The orientation of pipes will be that of the receiving system. You can then tidy this up, save the combined file and make runs as required.

This process is demonstrated by opening the file shown as **`Toowoomba Addition.drn`** in Figure 3.60 and creating a merge file named **`Toowoomba Addition.mrg`** with **the Export a Merge File** option in the **File** menu.

This can then be imported into **`Toowoomba Estate.drn`**, displayed in Figure 3.23, using the **Import a Merge File** option in the **File** menu. The joined system is shown in Figure 3.61.

It is possible to join models together when these do not have common pits, by drawing top dummy pits. The process is as follows:

(a) On the first model, draw two dummy pits 100 m or 200 m apart. Give them distinctive names. Pit details should be filled in, but the exact information entered is not important.

(b) Export the model data to a spreadsheet using the procedures in Section 3.5.4.

(c) Open the second *DRAINS* model and export the data from this to another worksheet in the spread sheet. Among the PIT/NODE outputs insert two additional rows.

(d) Return to the worksheet created from the first *DRAINS* model and copy the two rows describing the dummy pits. Paste these into the two blank rows in the worksheet for the second model. Then copy the whole worksheet to the clipboard.

(e) Return to the second *DRAINS* model and use the Edit → Paste Data from Spreadsheet option to bring the two dummy pits into this model.

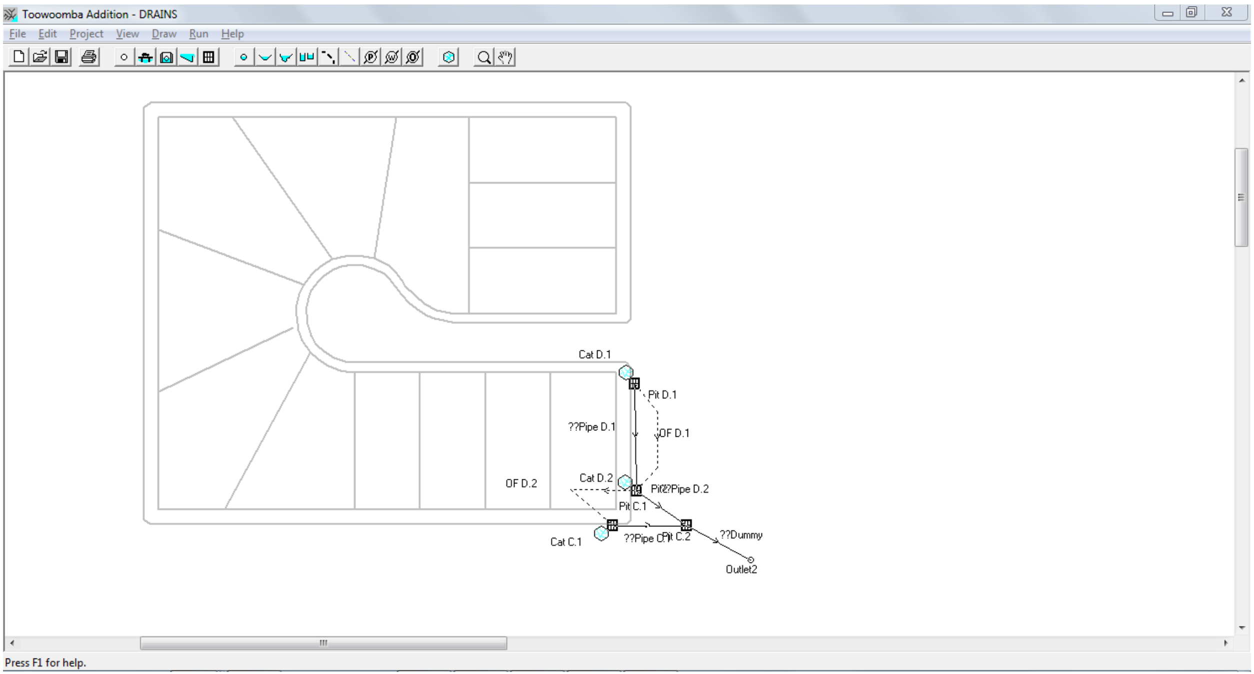


Figure 3.60 The File that is to be Added using the Merge Options

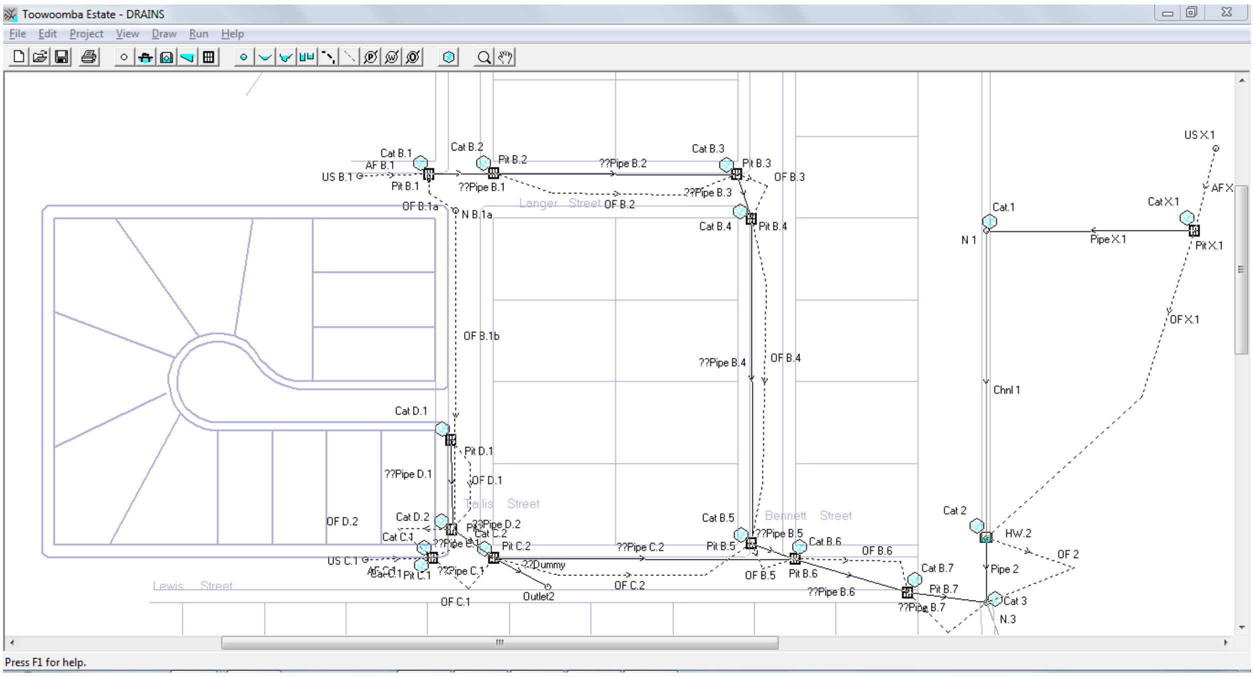


Figure 3.61 The Combined File

Both models should than have two common pits and can then be joined using the merge procedure described earlier in this section. If necessary, the background can be replaced using the procedures described in Section 3.2.2(b). A problem may occur if there is a conflict in the 'id' numbers that are used by DRAINS for internal purposes, and which appear in the spreadsheet output. Contact Watercom Pty Ltd if this occurs.

3.5.9 Template File Exports

To assist in the preparation of files that can be used as the basis of other models, *DRAINS* has a function implemented by selecting **File → Export → Drains template file….** This opens the following window:

After selecting a file type and clicking the Next button, a window appears allowing the file name and path to be nominated, and it can then be saved.

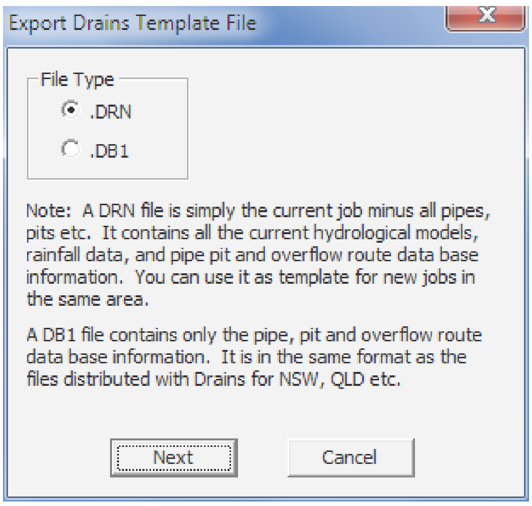


Figure 3.62 Dialog Box for Exporting Template Files

3.6 Help Options

The Help system in *DRAINS* can be called in three ways: (a) by choosing **Contents** in the **Help** menu, (b) by pressing the F1 key, or (c) by pressing a **Help** button in a property sheet or dialog box to deliver context-sensitive Help.

It is implemented as a HTML Help system in a three-pane window with an index as well as topics, as shown in Figure 3.63. The panes can be re-sized as required.

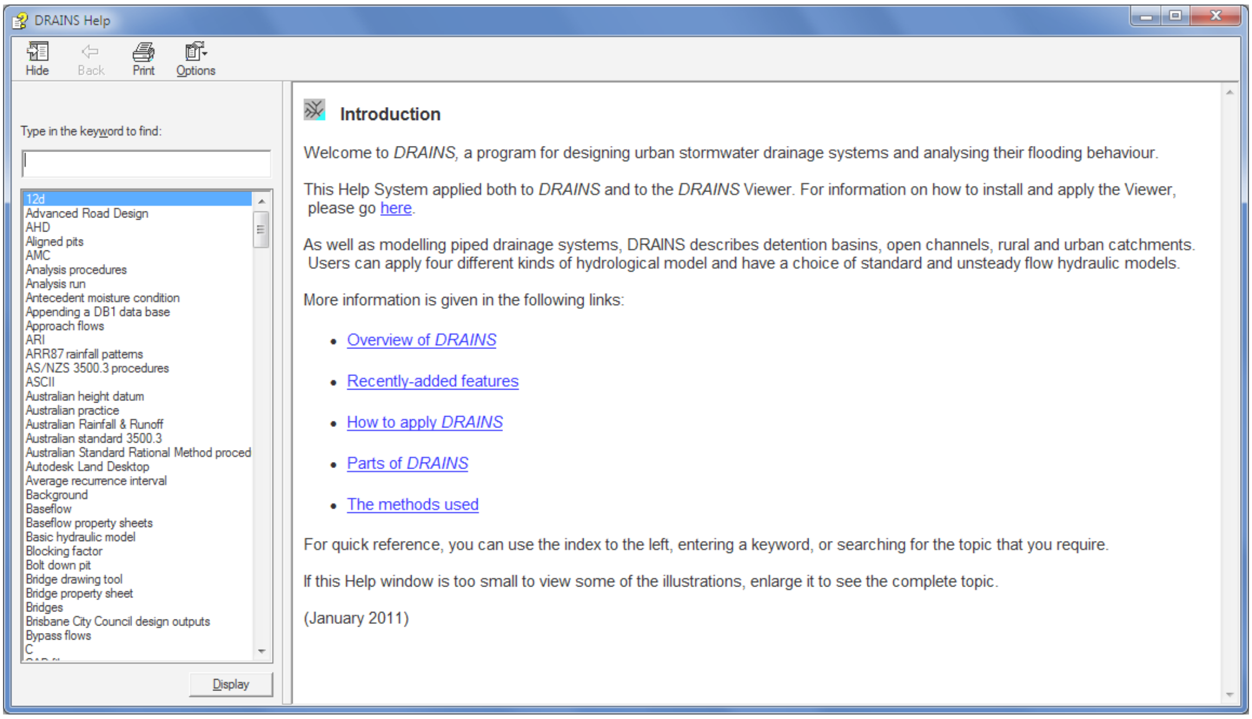


Figure 3.63 A Typical HTML Help Message

Within particular Help topics, the underlined links open additional topics. The index can also be used to find specific topics.

With well over 200 topics, the *DRAINS* Help system provides a comprehensive guide to the program, and a glossary of urban stormwater drainage terms and concepts. It complements the material in this manual, and provides timely advice on enhancements to *DRAINS*.

4. OPERATIONS

4.1 Introduction

This chapter outlines how *DRAINS* works and how to perform design and analysis tasks. The detailed procedures within the program cannot be explained in simple terms, so only a general description is provided here. Likewise, *DRAINS* can be put to many uses, and it is not possible to cover all of these. The *DRAINS* training workshops provide information of this type though examples and exercises.

4.2 *DRAINS* Workings

4.2.1 Units

DRAINS uses metric units throughout. Where possible, it follows SI conventions for these, but in many displays and outputs it is not possible to show superscripts. Thus, 'cu.m' and 'cu.m/s' are frequently used in place of 'm^3' and 'm^3/s'.

4.2.2 Programming

DRAINS is written in C++ and works on PCs with Microsoft Windows operating systems from Windows 95 to Windows 7. The calculation procedures from the PIPES program are used to model pressurised flow situations. It inputs and outputs data in binary, spreadsheet CSV, DXF, ESRI shapefile, MapInfo MID/MIF and data base formats.

DRAINS is structured so that different hydrological and hydraulic models can be run via the same interface, with many functions being shared, such as the display of hydrographs. There are choices of:

- Hydrological models - ILSAX, storage routing and extended rational method (producing hydrographs) and rational method (producing peak flowrates);
- Hydraulic calculations – standard or premium hydraulic model calculations, and perhaps for older models, the obsolete basic model calculations; and
- Procedures – design of pipe systems or analysis of pipe, open channel and detention systems.

The free *DRAINS* Viewer operates in the same way as *DRAINS*, but is limited to inspecting data and results saved in a .drn file. It can also export spreadsheet and CAD outputs.

4.2.3 Data Storage and Files

To run, *DRAINS* requires run specifications, rainfall data and a pipe or channel system. This data is stored temporarily in the computer's memory and, more permanently, in a binary data file with a **`.drn`** suffix, such as the sample files that have been described in this manual. After a data file has been saved, you can re-open it in *DRAINS* and modify the data. Since it is saved in binary format, it cannot be viewed or changed using a text editor. The binary file formats change as *DRAINS* is updated, but will always be back-compatible. That is, the current version of *DRAINS* will open and operate with files created in previous versions. You will probably not be able to open files created with a later version of *DRAINS* than the one you are using - it is not forward-compatible.

Each *DRAINS* **`.drn`** file is effectively a data base describing a drainage system and its components, together with reference data bases for pipes, pits and overflow routes, and possible the results of a run. Most of the data on the drainage system can be readily accessed in ASCII or text form, using the spreadsheet output option described in Section 3.5.4. Data on rainfall patterns, hydrological models and run specifications are not transferred to spreadsheets.

As well as the sets of pipe, pit and overflow route types and associated information contained in the **`.drn`** file, a set called **`Drains.db1`** is contained in the **`C:/Program Data/Drains`** folder. This is set that is applied when *DRAINS* is first .opened. The regional sets of pipe, pit and overflow route data for New South Wales, Queensland and other states are stored as **`.db1`** files in the **`C:/Program Files/Drains/Program`** folder, along with the **`Drains.exe`** file. These sets can be installed using the **Default Data Base** option in the **Project** menu, which copies these to **`Drains.db1`**. (It is important that users determine what they require before starting a project, as it may be awkward to change the available options later.)

4.2.4 Processes

As shown in Figure 4.1, you can operate *DRAINS* through a number of processes, such as:

(a) Data entry and file storage,

(b) Performing calculations,

(c) Inspection and possible storage of results,

(d) Changing or correcting data, and re-running calculations,

(e) Transferring data and results to files and other programs.

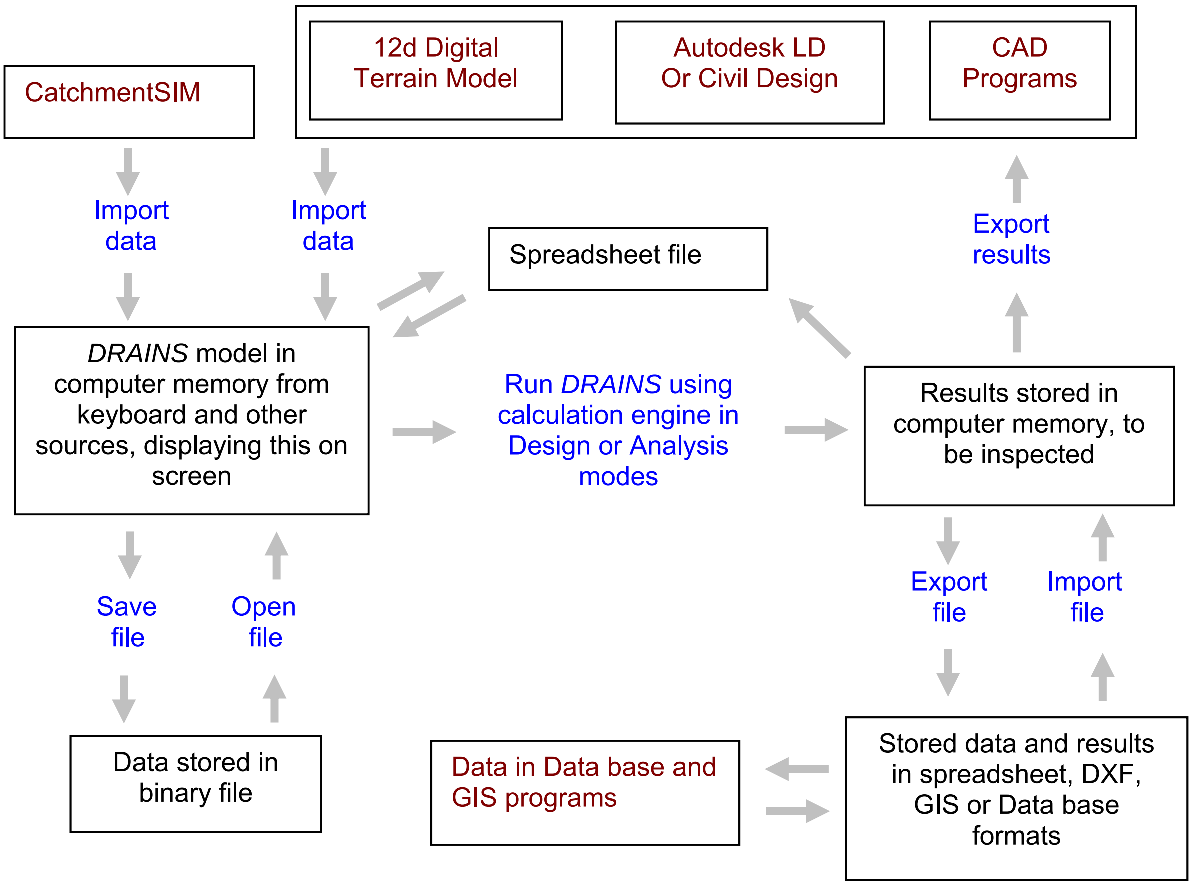


Figure 4.1 Typical Processes in *DRAINS*

Performing calculations in Action (b) is a batch process. Once started it continues without intervention by the user, unless it is aborted by pressing the **Esc** key. On the other hand, Actions (a), (c) and (d) are event-driven. They can be carried out in many different ways, depending on your preferences. The programming style follows Microsoft Windows conventions, so that it will be familiar to most users.

The main calculation procedures in *DRAINS* are:

- hydrological calculations, which produce the flowrates to be transported through the drainage system,
- the hydraulic design procedure for pipes, which determines pipe diameters and invert levels allowing for minor and major storms, and,
- hydraulic analysis calculations for pipes and channels, which define flow characteristics such as discharge rate, velocity and depth, and determine whether systems can convey flows without overflowing.

Applications using hydrological storage routing models may only apply the first of these procedures.

4.2.5 Initial Processes

The various run options are described in Section 3.4. Before these become available in the **Run** menu, DRAINS performs checks to confirm that:

- a hydrological model and rainfall patterns have been specified,
- the components of a system are joined correctly,
- the drainage system components have been fully specified.

The run options in the menu are greyed out if these conditions are not met.

Once a run begins, *DRAINS* sorts through the various components to define linkages throughout the system and the order in which calculations should occur. Using the coordinates of the objects, it identifies connections between pits or nodes and links, such as pipes or channels where the positions of the ends of a link are within the symbol of a node in the Main Window. The connections between pits and sub-catchments are established where the symbols overlap. The pits or nodes at the extremities of drainage systems are identified as those having no incoming links. *DRAINS* also checks inputs for any inconsistencies that have escaped the checks in property sheets during data entry.

4.2.6 Hydrological Calculations

With the ILSAX model, hydrological calculations involve the computation of the hydrographs from the paved and grassed surfaces of each sub-catchment using the Horton loss model and the time-area routing methods described in Section 5.3.2(b). They are carried out in the same way for both Design and Analysis runs. With the extended rational method and the storage routing models, hydrographs are calculated by different procedures. The rational method procedure only calculates peak flowrates.

In calculated hydrographs, flowrates are defined at times that are multiples of the calculation time step that is (a) defined in the **Options** property sheet called from the **Project** menu, or (b) automatically defined by *DRAINS* using various criteria, including the requirement that unpressurised flows should take at least one time step to travel through any pipe in the system.

DRAINS results change when it is run with different time steps. Most of the time, users should accept the time step defined by the program. This is determined so that it will take at least one time step for water to travel through each conduit. The minimum time step is 0.005 minutes or 0.3 seconds, and the maximum for pipe calculations is 1 minute. Sensitivity tests can be carried out to determine a suitable time step. If two time steps provide essentially the same results, the longer one can be used. Generally, smaller time steps will give more accurate and stable results, but this may not always be the case.

The hydrographs in all links begin at the same time, the start of the storm rainfall pattern. Any baseflows and user-provided inflow hydrographs introduced at pits or nodes begin at this starting time. User-provided hydrographs can be specified at any time step, but flowrates will be converted to the calculation time step by linear interpolation.

Where flow values are zero, due to:

- losses absorbing the initial rainfalls,
- a lag time or factor being specified for a grassed area hydrograph in the ILSAX model (see Section 2.3.5), or
- a delay used to model a moving storm (also see Section 2.3.5),

an appropriate number of zero flows will be placed at the start of the hydrograph so that it begins at the rainfall pattern's starting time. This common starting time simplifies the combination of hydrographs at junctions.

With the rational method model, peak flows are calculated and stored with the data for each component. Hydrographs produced by other models for sub-catchments, pipes, channels, overflow links and detention basins can be viewed as graphs or tables using the pop-up menus for individual components, and can be transferred to the Clipboard, as shown in Figure 5.3. They also can be printed out in the **Print Data and Results…** option in the **File** menu. Calculated hydrographs and HGL levels are stored temporarily as part of each sub-catchment 'object', and can be retained in the saved **`.drn`** file.

The procedures for the storage routing models emulating the RORB, RAFTS and WBNM models, are simpler than those from ILSAX. Results are presented in the same way as ILSAX hydrograph outputs in Figure 4.2. .

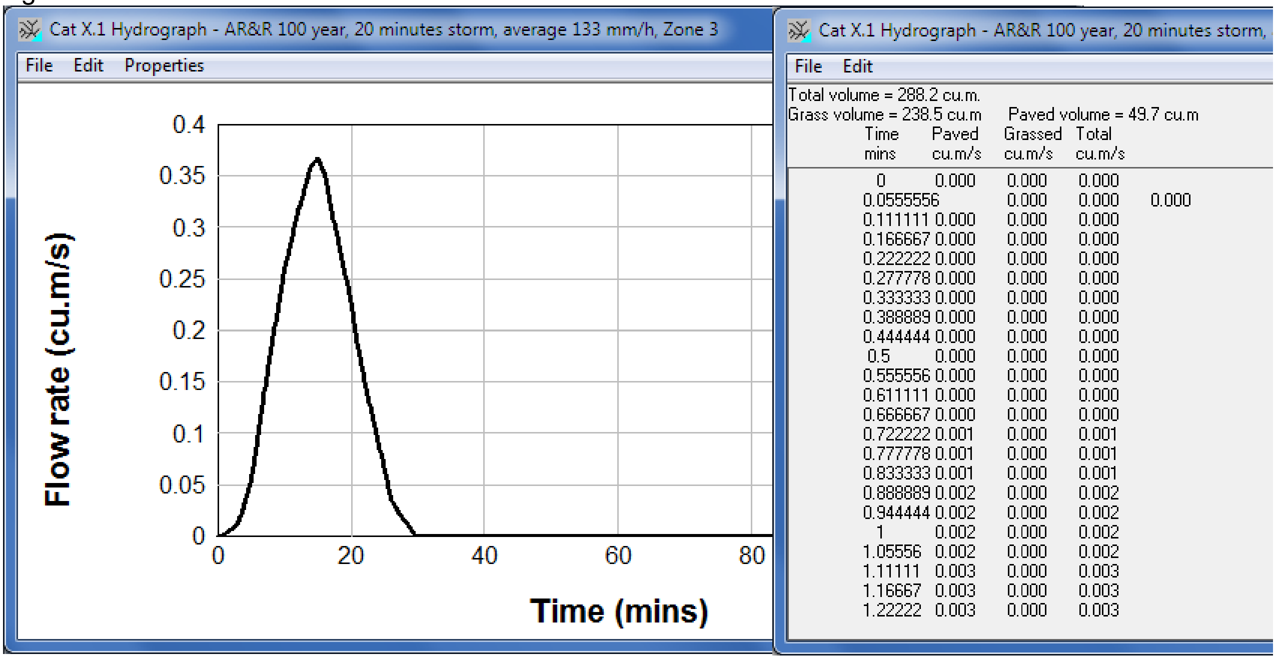


Figure 4.2 *DRAINS* Hydrograph Outputs for an ILSAX Sub-Catchment

4.2.7 Hydraulic Calculations

(a) General

Once hydraulic calculations begin, *DRAINS* determines the inflow into the pipe and channel system at each time step. At each node, the following flows are combined: flows off areas on the local sub-catchment, any overflows from upstream pits or detention basins that are directed to this destination, any baseflows or flows from user-provided inflow hydrographs applied at the surface for a pit or simple node.

This surface flow is assumed to enter the system without restriction at a simple node, detention basin, culvert or bridge. For an on-grade or sag pit, the pit capacity relationship defined in the Pit property sheet is applied to estimate the inflow rate, as described in Section 2.3.2.

For Design calculations, a pipe system will be sized to carry all flows that enter the system. The only overflows will be the bypasses caused by restrictions on inlet capacities. In Analysis, there may be upwelling of flows from the pit due to the capacity of the downstream pipe system being insufficient to carry the assumed flows. As shown in Figure 4.3, these are added to any bypass flows to define the total overflow from the pit.

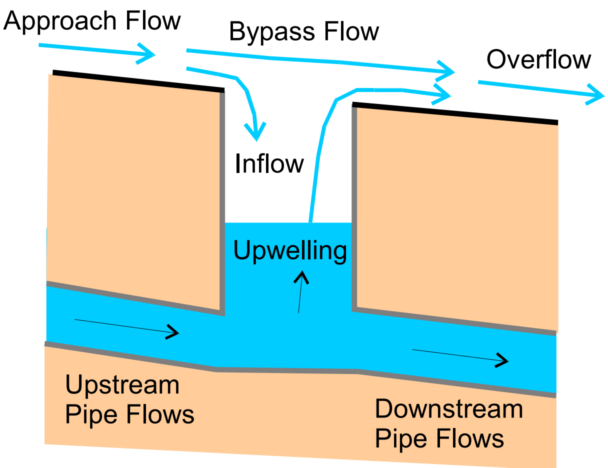


Figure 4.3 Pit Inflows and Outflows

No overflows can occur at simple nodes or from ILLUDAS type pits (now obsolete). Situations where overflows or breakouts occur from channels might be modelled by adding a detention basin at the overflow location, as noted in Table 2.2.
The calculated inflow rates at each time step can then be used as boundary conditions for the main set of calculations through a pipe or open channel system. These provide information on HGLs and water surfaces at nodes, and flowrates through the various links within a system.

With the rational method, only peak flow conditions are considered, but for hydrograph models, conditions are calculated at each time step..

(b) Basic Hydraulic Calculations

In the basic calculations that are now obsolete, drainage systems are analysed by making downwards and upwards passes through the pipe or channel network at each time step, going from each pit or node to the next one downstream or upstream. The first pass moves downwards from the top of each line in the system, establishing the surface flows arriving at each node by adding flows from the local catchment, overflows from upstream and user-provided flows. Using the pit inlet capacity relationship, bypass flows are determined. The flow entering the pit is then added to any flows through upstream pipes and possible user-provided inflow hydrographs to define provisional pipe flows.

When the calculations reach the system outlet or outlets, *DRAINS* makes the upwards pass, starting from the tailwater level at the outlet. Allowing for pipe friction and pressure changes at pits, it defines the position of the HGLs at pits and nodes, and if necessary, modifies the flowrates in the pipes and the corresponding overflows. For part-full pipe flow, this process is carried out by projecting HGLs upwards and allowing for pressure changes at pits. If a pipe flows full, a pressurised flow calculation procedure is used to define HGLs at pits and flowrates in pipes. Whenever it encounters a junction, *DRAINS* projects HGLs up both branches from the pit water level. If the calculated water level in a drop pit is determined to be below the invert level of an incoming pipe, the tailwater is set at the critical depth in this pipe, and upwards HGL projections are continued.

This model provides information on water levels at pits and nodes and flowrates through pipes. When there is subcritical open channel flow, the standard step method employing the Colebrook-White or Manning's equation is used to compute backwater curves in pipes and channels. Where pipe flow is supercritical, the water surface is assumed to follow the normal depth. (In open channels, the basic model conservatively assumes surfaces to be no lower than the critical depth.)

The basic calculations define HGLs at nodes and inside pipes for subcritical part-full flows, but they only presents the results at nodes. They define flowrates in links such as pipes or channels, and provides continuity checks in the spreadsheet output summing the inflows and outflows at each node. The flowrates presented for pipes are those calculated at their upper ends, so that the flows displayed in *DRAINS* outputs at a particular time will probably differ from the flowrates emerging from the pipe at that time. If a pipe is unpressurised, these outflows will be the same as the flows that entered a conduit a certain number of time steps previously (depending on the pipe length and flow velocity). If it is pressurised, there is no time delay. *DRAINS* manages the transfers between part-full and full-pipe flow so that there are only small continuity errors.

(c) Unsteady Hydraulic Calculations

The unsteady flow calculations carried out with the standard and premium hydraulic models are quite different, using the equations of mass and momentum conservation (Section 5.6.4) to set up a matrix specifying the equations to be solved over a space-time grid. The space or x dimension represents the conditions at various points in a system, with conditions being calculated at multiple points in longer conduits. The time or t dimension relates to the time steps used. While results are reported at fixed times, calculations can be carried out at smaller time intervals. The main quantities being calculated are water elevations H and flowrates Q. The main calculation involves the solution of the matrix equations to determine H and Q values at all locations at each time step during the simulation. As well as the core calculation procedures, this involves the determination of states at many boundaries in the system (such as pits where water enters, and outflow locations).

Water or HGL levels are presented at pits and nodes and also appear on some plots of pipe, overflow route and open channel long-sections. The flowrates displayed apply at the centre of the link.

The *DRAINS* hydraulic calculation procedures permit two outlet pipes to be specified for each pit, and can model looped or branching pipe systems, where there is a bifurcation with two pipes coming out of a pit. The premium hydraulic model permits two or more overflow routes from sag and on-grade pits, so the

invert levels of overflow routes from a pit can be at different levels. This allows modelling of situations that cannot be adequately modelled using the basic or standard models (e.g. overflow from an on-grade pit down a gutter and across the road crown).

(d) Pit Modelling

As flows pass through pits, a pit pressure change relationship is applied, using the k_u factor shown in Figure 4.4, which is specified by the user in the pit's property sheet.

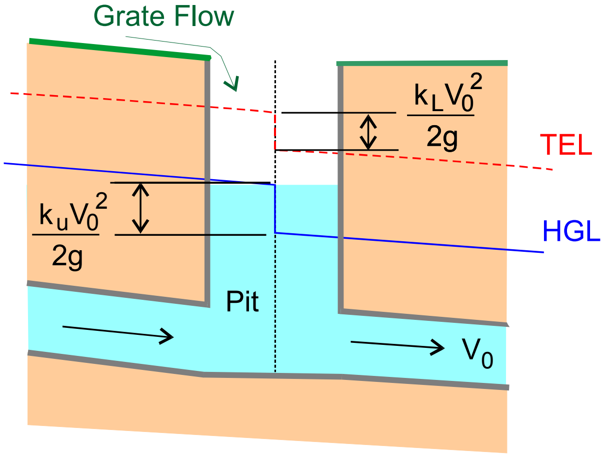


Figure 4.4 Pit Pressure Change Relationships

The change from part-full to full pipe flow often results in a large increase in the pit pressure change. This raises the HGL level and causes a rise of HGL that moves upwards through the system. A jump in pressure at a pit may actually be due to filling of another pit somewhere downstream. A similar drop in HGL and pressure may occur when a full-flowing pipe changes to part-full flow.

While pit pressure changes have been studied for full-pipe flows, there is little information available about pit pressure changes and energy losses in pits with part-full flow. Currently, DRAINS assumes that k_u coefficients are constant , and the same for both full- and part-full flows. This is likely to be conservative, overestimating changes for part-full flows. It also provides more stable results.

If a sag or on-grade pit is defined as being sealed using the check box labelled 'Pit has bolt down lid' in the Pit property sheet, the HGL can rise above the surface without any upwelling occurring. *DRAINS* calculates upwelling flows using hydraulic analyses. With the basic hydraulic model, no outlet restrictions are placed on upwelling flows unless the pit has a bolt-down lid. With the standard and premium hydraulic models, a hydraulic loss is assumed to occur when water upwells. This is based on the sag pit depth-inflow relationship for the pit type and size being used.

(e) Tailwater Levels

At system outlets, *DRAINS* sets a tailwater level, depending on the entries in the Outlet property sheet. If a free outfall is specified, it determines the higher of the normal and critical depths for the current flowrate. If a higher tailwater level is specified in the property sheet for the particular storm being analysed, this level becomes the starting point for an upwards projection in the obsolete basic hydraulic model and a boundary condition in the current unsteady models.

Where a drop pit is so deep that the pit water surface is below the invert of the upstream pipe, the starting level for upstream HGL projections will be set in the same way as for a free outlet. It will be the higher of the normal and critical depths in the upstream pipe. In effect, the calculations start again at this pit.

(f) Surface Overflows

Overflows follow the defined overland flow path to a destination, with flows being lagged by the specified time delay, which must be at least one calculation time step.

Although a slope and cross-section must be specified for flow paths, the standard hydraulic method calculations allow a flow to go from one pit or node to another at a higher surface level, despite warnings that are displayed by *DRAINS*. The premium model is stricter, and all overflow paths must have downwards slopes. In this model, overflow routes are modelled in the same way as open channels, and backwater effects can apply.

(g) Detention Basins

The calculations for detention basins in *DRAINS* can be complex because the elevation-discharge relationship will change if the downstream tailwater level submerges the outlet. This can happen at many time steps during a *DRAINS* run, so that the relationship changes. By contrast, ILSAX and most other models for trunk drainage systems assume that the relationship is fixed. Thus, *DRAINS* can model interconnected basins.

Flows through culverts and bridges are modelled using the same equations as outflows from detention basins, since they obstruct flows and can have low level outlets (the channel under the roadway) and high level outlets (overflows over the road). They do not have any associated storage. Where this may be significant, the situation can be modelled as a detention basin. *DRAINS* returns similar information in the Main Window for detention basins, culverts and bridges - the upstream and downstream water levels.

4.2.8 Calibration

This process of fitting a hydrological computer model to observed or recorded information is done by varying the model parameters. Some calibrations made using *DRAINS* and similar models are presented in Sections 5.3.3 and 5.3.5. In *DRAINS*, the main factors that can be varied are:

- the soil type, depression storages, and AMC,
- the proportions of paved, supplementary and grassed areas,
- the times of entry for paved, supplementary and grassed areas.

All of these relate to physical quantities that are easily understandable, so that values that are estimated, as is usually the case, will not be greatly wide of the mark.

Where rainfall and runoff data for storms is available, the hydrological modelling in *DRAINS* can be improved by calibration, though not to a large extent (O'Loughlin, Haig, Attwater and Clare, 1991). Times of entry and travel through a drainage system can be defined more accurately. Less accurate calibrations can also be carried out based on ponded volumes. If rainfall is available for a storm, *DRAINS* can estimate the stored volume at a location where depths have been observed. The volume from *DRAINS* can be compared with that corresponding to the maximum depth observed.

Calibration of drainage system hydraulics is usually performed by altering the roughnesses of conduits to match observed water levels. Observations may often be available for open channels, but are unlikely to be available for closed pipe systems, unless a special gauging programme is undertaken. If such information is available, it can be used to verify the *DRAINS* model, though it is likely to be difficult to refine the model because of the many pipe links that may be involved.

4.2.9 Interpretation of Results

Most DRAINS hydrographs and HGL plots are simple 'rise and fall' patterns, reflecting the simple design rainfall patterns that are commonly used. However, in complex or badly-implemented pipe systems, complex patterns such as the hydrograph shown in Figure 4.5 can occur.

A *DRAINS* plot may show frequent rises and falls at some times, giving rise to 'black ink'. The plot also shows a flow peak that has caved in, or reversed itself. This can occur when the HGL at the pit upstream of a pipe overflows, while the HGL at the pit at the downstream end is still below the ground surface. As flowrates increase, or tailwater levels rise higher, the HGL level in the downstream pit rises, flattening the HGL for the pipe and reducing the flowrate through it. This produces the 'hollowed out' effect.

The hydrograph in Figure 4.5 also displays negative flows, indicating that there has been a flow reversal. Flows can reverse in any DRAINS model if the HGL slope is negative, but this occurs rarely. In this case, a high HGL downstream causes flows to run backwards.

These can also be sudden 'spikes' and instabilities that occur at very low flows, due to waves that are numerically generated. Users should interpret plots with strange patterns to understand what is going on. Often this requires inspection of two or more flow and HGL plots together.

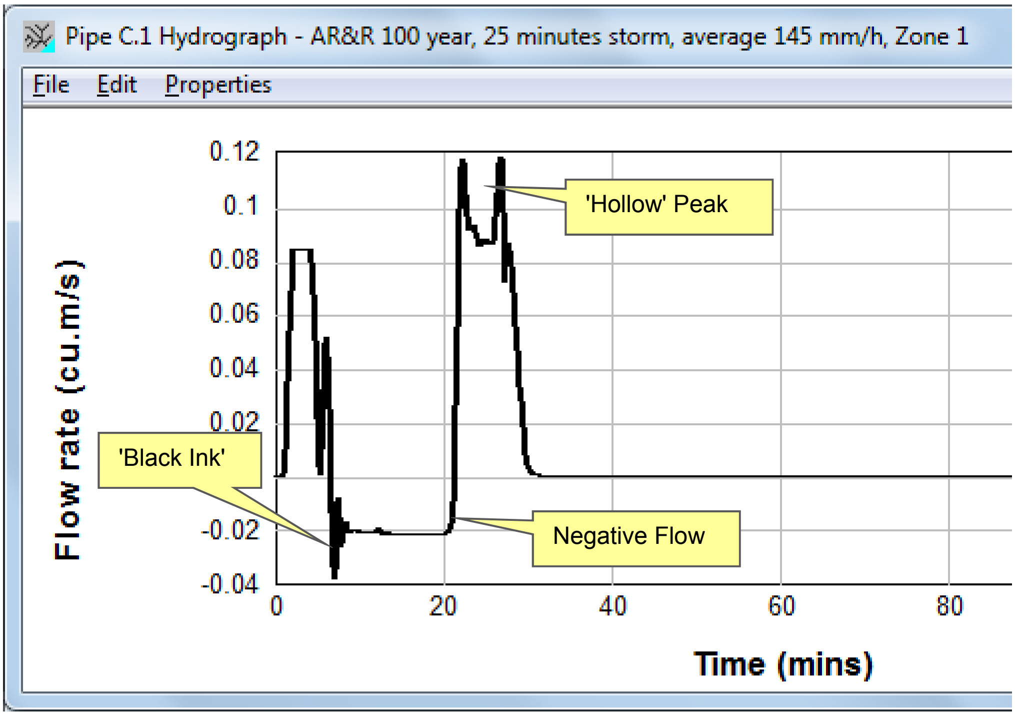


Figure 4.5 Complex Flow Hydrograph

4.2.10 Design Procedures

The pipe design process in *DRAINS* makes a pass down the various branches of a drainage network from pits at the tops of lines to the main outlet. At each pit, it determines the maximum pipe outflow, allowing for inlet flows, flows in upstream pipes, and any baseflows or user-provided direct hydrograph flows. It then determines suitable pipe sizes and invert levels, taking account of:

- the roughness and the allowable cover depth associated with the chosen pipe type,
- the values set of minimum pipe slope, pit freeboard and fall in the **Options** property sheet opened from the **Project** menu,
- a restriction preventing pipes decreasing in diameter as the calculations move downstream,
- likely pit pressure changes at pits in full or part-full pipe flows, and
- the hydraulic capacities of pipes with various diameters and slopes.

In 2014, an enhanced design procedure has been introduced. Following a design by the original procedure, a review is carried out that reduces pipe sizes where possible. It provides a message saying how many pipes were able to be downsized. Pipes reduced by more than one size increment will only be counted as one pipe downsize.

It may still be possible to improve on a *DRAINS* design by manually downsizing pipes, although there is much less scope to do this than with the original design procedure. If you try to do this, some things to keep in mind are:

- You should not make any pipe smaller than the biggest pipe upstream (i.e. if you have a run of say, 1200 mm pipes, you could try to downsize the one furthest upstream. If you can'y downsize this, you will not be able to downsize any pipes in the run.
- For major storms you should use the same freeboard criterion as set in **Project** → **Options**. If you want to relax this criterion for major storms, you should also relax it in **Project** → **Options** prior to a design run in *DRAINS*.

The selection of invert levels is mainly based on allowable cover depths and slope restrictions. The aim is to keep the pipe as shallow as possible, and pipe sizes are increased where necessary to achieve this. (In cases where pipes need to be set deep enough to pass under other services, such as water supply pipes, increased cover depths can be defined in the **Project** → **Options** property sheet, effectively specifying a minimum pipe depth.)

Allowance is made for cover depths at intermediate levels along a pipeline, as defined in the Survey Data property sheet called from a Pipe property sheet (see Section 2.3.4). A result is shown graphically in Figure 4.6. This output also shows a pit with a significant drop, which might be a consequence of aiming to keep the pipe system as shallow as possible. If you wish to grade the upstream pipe down to the pit, it will be necessary to adjust the invert levels and run the model in Analysis mode, or make the pipe inverts fixed.

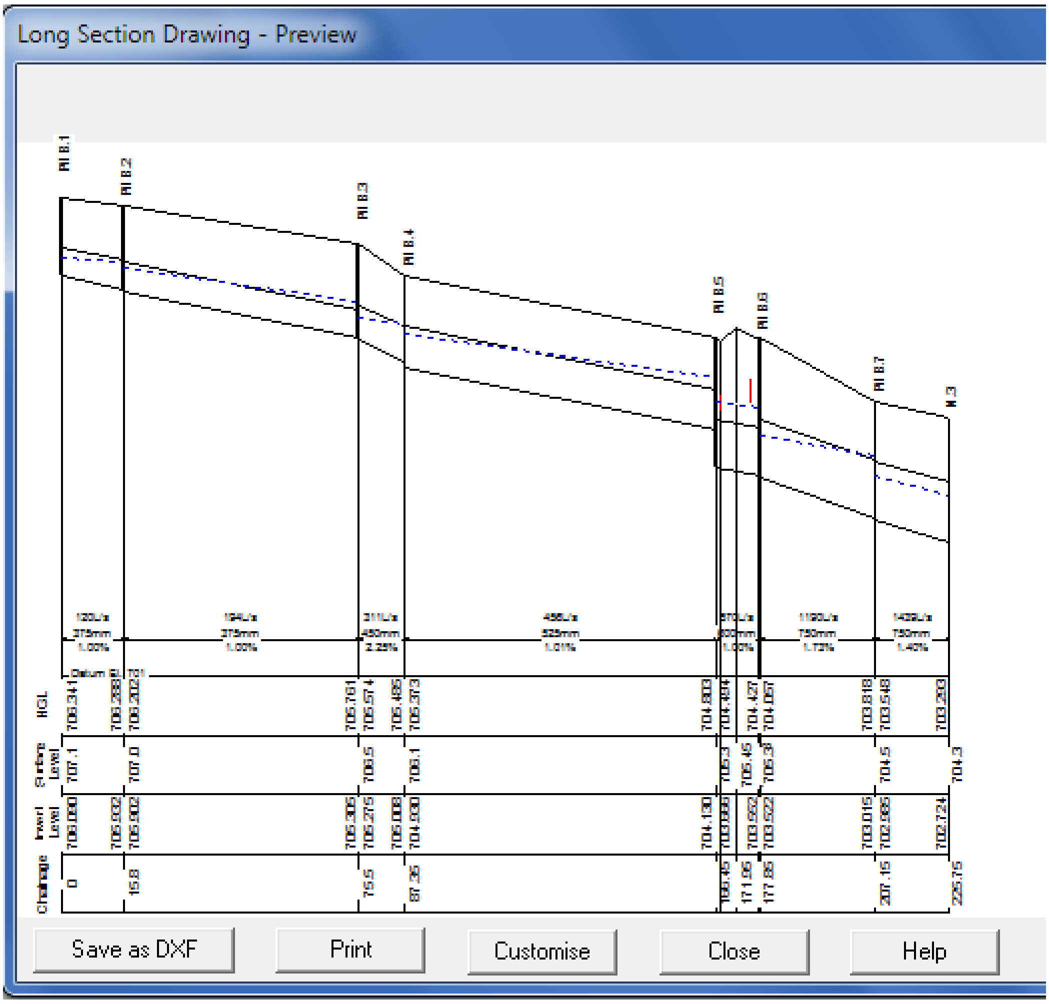


Figure 4.6 Display showing a Drop Pit and Intermediate Levels

DRAINS can automatically design to avoid fixed services, where possible, using service location information entered in the Survey Data property sheet and a minimum design clearance to services set in the **Options** property sheet called from the **Project** menu. One such service is shown in Figure 4.6 and also in Figure 4.7.

If a Design run is made with the positions of some of the pipes fixed, the results must be carefully checked, especially if these are located in the middle of lines. In some complex Design cases, pipes entering pits might be lower than a fixed pipe flowing out. The fallback in this case is to run in Analysis mode with pits and pipes made 'existing', and to vary pipe sizes and invert levels individually to achieve a satisfactory design.

Where multiple storm patterns are specified, the program repeats the downwards pass for each storm and selects the pipe diameters and invert levels that convey the most critical flows.

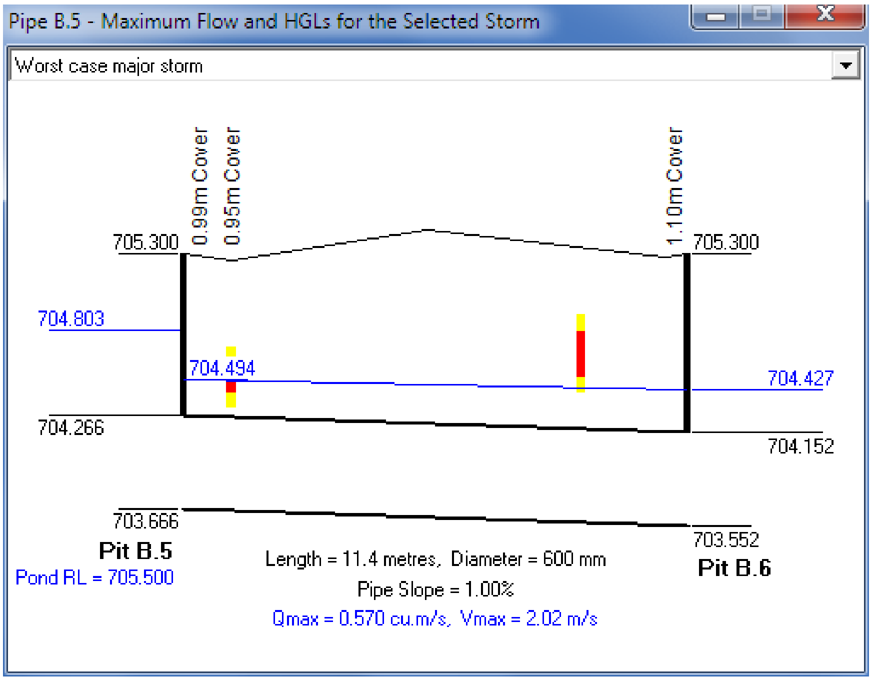


Figure 4.7 Long Section Display (from Pop-Up Menu for a Pipe

The design procedure also determines the sizes of inlet pits, using a method that was first presented in the *Queensland Urban Drainage Manual* (Neville Jones & Associates et al., 1992). The method focuses upon the flows along overflow routes. It sets appropriate safety levels for these, in terms of tolerable flow depths in the minor and major storms and a maximum velocity x depth product. A point along each flow path must be nominated, by specifying a cross-section from the Overflow Route data base as shown in Figure 4.8, a percentage of downstream catchment contributing to the flow, and a longitudinal slope. The basis for selecting the percentage of the downstream sub-catchment is explained in Section 2.3.6.

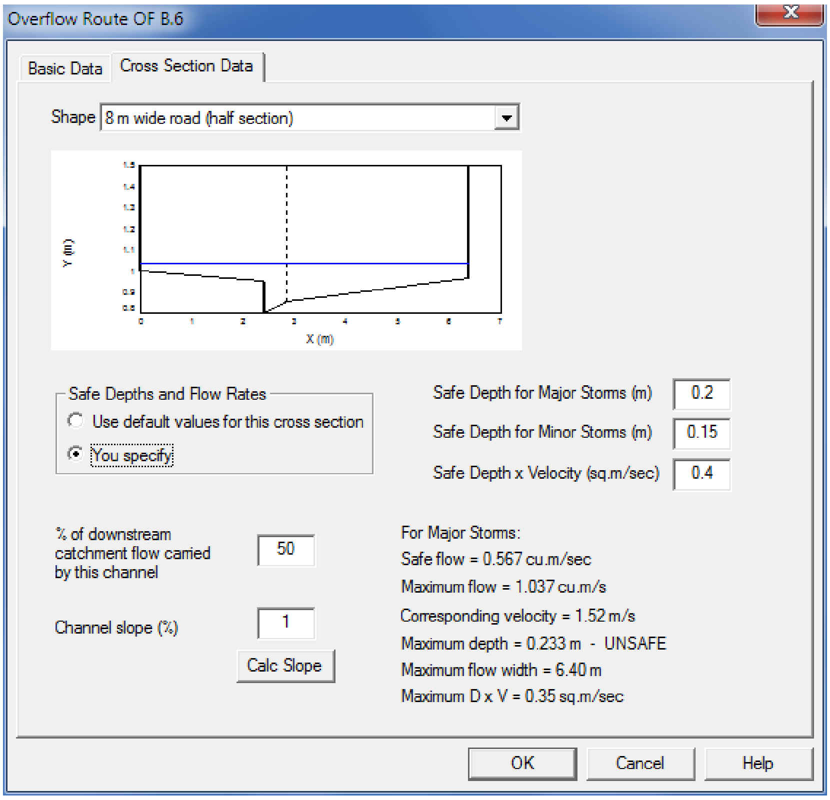


Figure 4.8 The Overflow Route Property Sheet

Having established safe flows for each flow path, the method then determines the pit and pipe sizes needed to restrict the surface overflows to the safe limits, considering both minor and major flows.

This process requires that pit types be classified into families and sizes, in a similar way to the classification of pipe types and diameters. With the user having defined the pit and pipe types required, *DRAINS* searches through the available sizes to determine the required ones at each overflow location. It also selects pipe sizes so that at a major storm level, such as the 100 year ARI storm event, HGL levels at pits are still below the ground surface. This ensures that the drainage system does not completely fill with water, and the pipe flows will be maintained even when stormwater ponds over pits.

In some cases, *DRAINS* cannot arrive at a solution that meets the safety requirements, most obviously when the flow from a sub-catchment is much larger than the capacity of any of the pits that can be selected. *DRAINS* returns the notice in Figure 4.9, advising that the pipe system must be changed or that different pits are required.

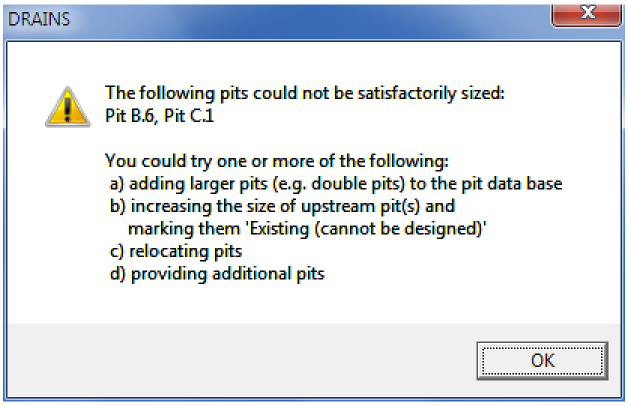


Figure 4.9 Warning of Failure to Define a Feasible Design

The results can be checked by Analysis runs to ensure that the design conditions are met. By taking full advantage of allowable surface flow capacities, the sizes and costs of pipe systems can be minimised.

4.3 Applying *DRAINS*

4.3.1 Integration

A key feature of *DRAINS* is integration. This occurs internally, with the data inputs, hydrology, hydraulics and presentation of results operating in the same package, and the ability to model different parts and scales of stormwater systems together. It also occurs externally, with the linkages to other programs shown in Figure 4.10.

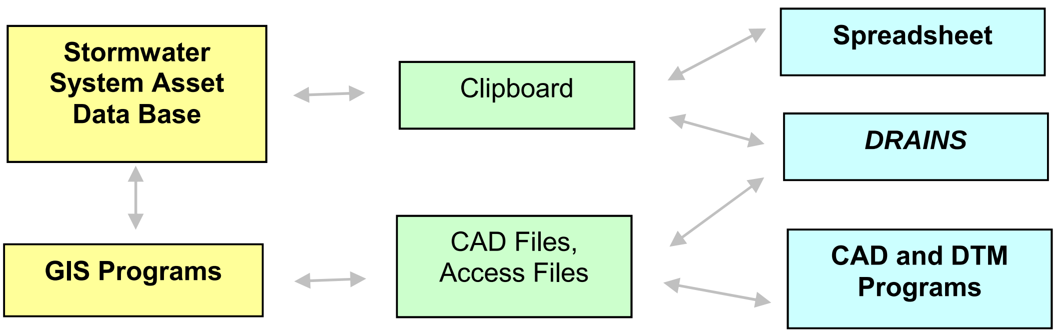


Figure 4.10 Integrated Linkages between *DRAINS* and other programs.

The general operation of DRAINS have been illustrated in Chapter 1. This section provides guidance on applications to specific types of stormwater drainage system.

4.3.2 Designing Subdivision Piped Drainage Systems

Design runs are mainly made for new systems on greenfields sites where the developer and designer have considerable scope to alter the system. The available information will be:

- a survey of the area showing contours to a standard datum such as AHD and a mapping grid such as MGA94, available on paper and electronically as a CAD file in a format such as DXF or DWG.
- the planned layout for roads, either on plans, or as a partly- or fully-completed road design model;

- cadastral (property boundary) data, available on plans and as drawing layers over which the contour drawing can be overlaid;
- the technical requirements of the consent authority for the project;
- local design rainfall data and other local information.

There is usually some give and take in design, so that the road and allotment layout can be altered to suit drainage requirements. However, the initial layout made by an experienced subdivision and road designer should anticipate potential conflicts.

The products or 'deliverables' of the design will be a drainage layer in the drawings with all drains and channels detailed, together with design calculations. Plans, specifications, tables of quantities and estimated costs can be derived from these.

The main aims in designing pipe networks with *DRAINS* are to develop a file that describes the proposed system, and to produce the deliverables - plans and documentation. The single `.drn` file can be run for both Design and checking by Analysis, and can quickly be re-run, with data and results being transferred to a spreadsheet or report. It forms the basis for the design variations and checks that may be required.

For a small system, data can be entered from the keyboard into property sheets, as described in Chapter 1. For larger systems, it is likely that information will be transferred from a CAD file, as described in Section 3.2.2, or from DTMs such as 12d and Advanced Road Design. Imported data can be augmented with data entered directly into the property sheets for components. The information for a component is retained when it is copied and pasted using the **Copy Shape** option in the pop-up menu for a component and the associated **Paste Shape** option. It is often easier to copy and paste an existing component and to modify its data, rather than to enter all data each time an object is created.

For large systems, the spreadsheet outputs and inputs described in Section 3.5.4 can provide an efficient means of entering repetitive data. Components can be entered with nominal values and can then be edited in the Data spreadsheet, before transferring the information back to *DRAINS*. The process is shown diagrammatically in Figure 4.11.

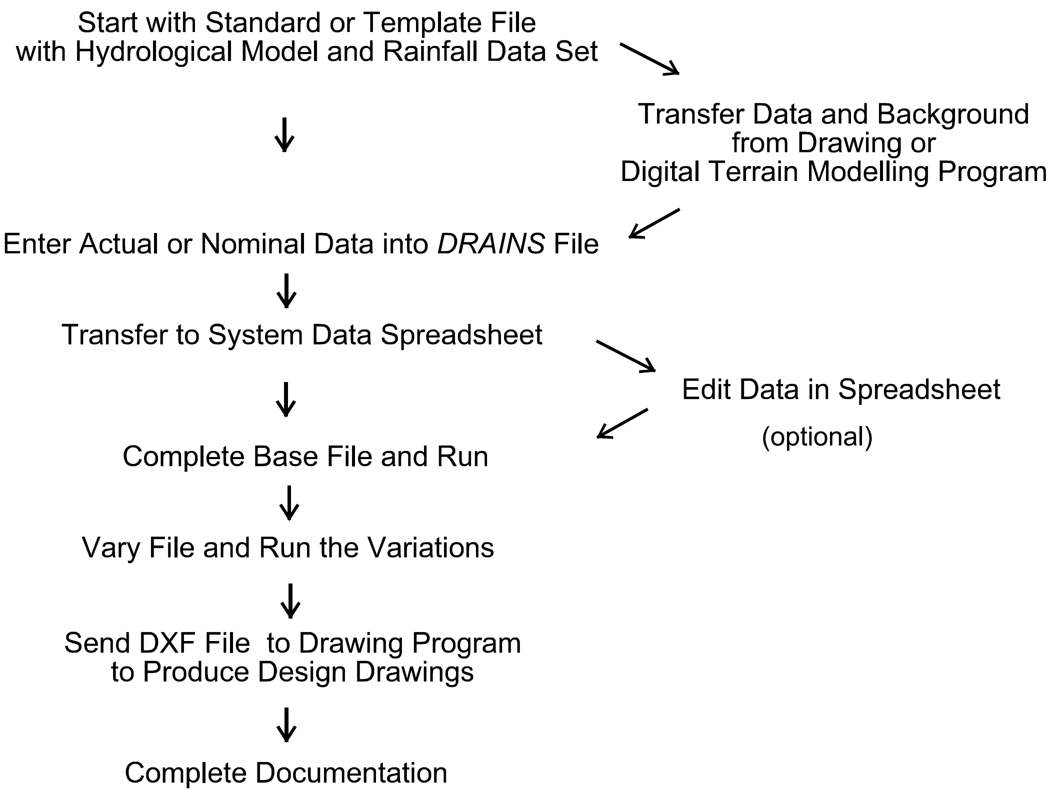


Figure 4.11 The Design Process

Using CAD and DTM programs, catchment areas can be defined as polygons and the areas directly measured. The lengths of flowpaths, and in some models, their slopes, can also be determined. In some models, the automatic definition of impervious and pervious areas will be possible where suitable overlays are available.

For convenience in design, the parts of the system can be separated into small sub-systems. For example, where several branched pipe systems in steep terrain flow to a common open channel, the pipe systems can be analysed independently, as long as there are no backwater effects. In flat terrain with backwater influences the system must be designed as a whole. Individual systems can be joined using the merging procedures described in Section 3.5.8.

DRAINS produces information on pipe sizes, invert levels and locations that can be transferred to drawing programs to produce detailed plans and longitudinal sections. The spreadsheet tables act as documentation that can be printed or supplied in electronic form to a consent authority, together with the *DRAINS* data files. Diagrams of the network can be printed, say as a PDF file using the **File → Print Diagram** option.

Models and results can be checked by persons inside or outside the designer's organisation using the *DRAINS* Viewer, which is free. A reviewer can open all property sheets in a model and export data summaries in spreadsheet format. If a *DRAINS* file contains stored results, these can also be viewed and exported to spreadsheets. CAD outputs and system diagrams can also be exported, but other types of output are not available. It is not possible to edit or run files in the Viewer. Since reviewers have direct access to models, it should not be necessary to provide elaborate printed sets of results to reviewers. However, some converter spreadsheets have been developed to transfer results from ILSAX and rational method models to tables similar to those in *Australian Rainfall and Runoff* and the *Queensland Urban Drainage Manual*. These are available as downloads from www.watercom.com.au (see the last item on the downloads page).

Since *DRAINS* runs rapidly and its results are quite apparent, it is easy for consent authorities such as municipal councils to run files and inspect the results, or else to view these using the *DRAINS* Viewer. As discussed in Section 4.3.4, files prepared by consultants can be retained and incorporated into the authority's *DRAINS* model of its overall drainage system.

The results provided by an appropriate ILSAX hydrological model are likely to be superior to those obtained using the rational method, since allowance can be made for multiple storms and detention storages, and major system modelling is more accurate. The extended rational method gets overcomes most of these difficulties, as it produces hydrographs using a rational method loss model.

The pipe system design method employed in DRAINS is dependent on having good information on pit inlet capacity relationships. The best data is available from Queensland where overflows are larger than in southern states, and more attention has been given to controlling them. If good quality pit capacity data is unavailable, the Design method cannot be realistically employed.

The design method can be applied with the rational method and extended rational method as well as the ILSAX hydrological model. The design calculations for sizing pipes and determining invert levels are carried out using simplified assumptions, and need to be followed by one or more analysis runs.

DRAINS allows hydrological models to be swapped easily, so that it is not difficult to convert rational method models to ones using ILSAX hydrology. Only the hydrological model and rainfall data need to be changed, and the impervious areas for each sub-catchment to be split into paved and supplementary areas. The reverse change, from an ILSAX Model to the rational method, can be done even more easily. This might be done to compare the results given by the models, or to check an older design using rational method hydrology.

4.3.3 Designing Infill Developments with On-Site Stormwater Detention Systems

Design work for re-developments, and developments located within established urban areas, is more complex that greenfields design. There are many more constraints, such as:

- the presence of existing infrastructure such as water pipes and electricity cables,
- the need to connect into an existing drainage system, which may create problems due to low availability of head and limited downstream capacity,
- the presence of multiple land-owners,
- difficulties of construction due to limited space and conflicts with traffic and other activities in the area.

It is unlikely that designs of pipe systems can be carried out automatically, as in a new subdivision. Analysis capabilities are required when exploring solutions. Users will probably have to vary some

features by hand to develop a trial and error solution. Fortunately, *DRAINS* can be easily edited and re-runs can be carried out rapidly.

While *DRAINS* allows users to mix pipes that have fixed inverts with pipes with positions that can be varied, it may not be able to develop with a suitable design in some cases. When dealing with a complex situation, a suitable strategy would be to see whether *DRAINS* can come up with a satisfactory design first, and then make modifications by hand to cope with problems such as conflicting services and the inability of a pipe system to match the inverts of the downstream pipe to which it must connect, while carrying the required design flows.

DRAINS can 'design around' existing services or utilities, and can allow for surface levels all the way along a pipe if suitable survey data is provided in the Pipe property sheet. However, the solution provided may set pipe inverts too deep, so that it will be necessary to make adjustments by hand. It may be necessary to use stronger pipe classes (with greater wall thicknesses), multiple pipes or box-section conduits to reduce the cover requirements. In complex cases, relocation of existing stormwater pipes or other services may be the best solution.

Because re-developments usually involve an increase in the density of development and the percentage of impervious area, several drainage authorities have imposed on-site stormwater detention (OSD) requirements. These have become an important and often complicated issue for designers. The Upper Parramatta River Catchment Trust has been the most influential developer of OSD design procedures in New South Wales, introducing requirements such as a permissible site discharge (PSD) in L/s/ha of catchment, and site storage requirement (SSR) in m^3/ha.

DRAINS models detention basins by simulation, presenting several relationships, such as storage vs. time, upstream and downstream water levels vs. time, and inflow and outflow hydrographs. It can also handle multiple outlets, infiltration into soils and pumped systems. The high early discharge (HED) system can also be modelled. Details are given in Section 2.3.7.

The detention basin routing has to be explored by trial and error, but the ability to edit the data quickly and re-run the model makes this a fast process.

4.3.4 Analysing Established Drainage Systems

Established systems may need to be examined for deficiencies at particular locations, such as problem areas, where complaints of flooding have been made by householders, or on an area-wide basis, taking in all drainage system components. This latter type of investigation may be prompted by asset management or liability concerns, rather than by particular experiences of flooding.

The processes in creating *DRAINS* files for Analysis are almost the same as for Design. However, all pits and pipes should be defined as 'existing'. Invert levels of all conduits must be defined.

The sources of the information required include:

- scaled plans showing road and cadastral layouts and contours,
- information on additions and remedial works for the drainage system,
- information on detention storage systems on sites or on public land,
- files detailing reports and complaints stemming from storm events and drainage system defects,
- any previous analysis studies relating to the area being considered,
- information on past storm events.

Since an existing system has to be modelled in some detail, it will be necessary to draw information from GIS and data base sources. If these are unavailable or inadequate, it will be necessary to carry out topographic surveys to determine the exact positions and levels of system components, including:

- surface levels of pits,
- invert levels of pipes, including if possible, those in sealed pits and junctions,
- lengths of pipes,
- floor levels of houses and businesses, and driveway levels where flows may enter properties and yard levels where ponding may occur.

Techniques such as GPS measurements and LIDAR aerial laser scanning, supplemented by conventional surveying, can be used to obtain large amounts of levels efficiently.

Inspections are needed to define many aspects of drainage systems, such as low points on roadways and likely overflow paths. It is likely that the same areas may have to be inspected two or three times during modelling to define drainage components and paths exactly. Information can also be sought from residents about their experiences of flooding during these visits. Closed circuit television (CCTV) investigations can provide detailed information on pipes and defects such as erosion, cracks and faulty joints.

If resources are available, the drainage system may be gauged to record storms rainfalls and corresponding drainage system flows that can be used to calibrate models. Rainfalls are usually recorded by tipping-bucket raingauges and pipe and channel flows by magnetic or laser-Doppler flow meters. Gauging for a period of at least 3 months will probably be necessary. When the model is run with recorded data, the times of flow can be varied by altering values in the spreadsheet output and re-inserting these into *DRAINS*. The *DRAINS* model can be calibrated or 'tuned' so that the times of the calculated hydrograph peaks match those of the recorded ones. A similar process can be carried out by varying the Hydrological Model parameters and percentages of land use, to make the calculated flow peaks or volumes match the recorded ones. This is more difficult because pervious areas may only contribute flows in larger storms, and the gauging period may be too short or dry to record significant runoff-producing storms.

From the available mapping and the survey data, DXF or DWG drawings can be prepared, and a suitable file prepared with the three layers containing pits (as circles), pipes and a background. DXF files then can be imported into *DRAINS* to provide the initial file for the data entry and modelling processes.

As in Design, it will be necessary to develop a set of guidelines on matters such as:

- the definition and modelling of flow paths,
- the factors used in pit inlet capacity relationships for the various kinds of pits encountered in the drainage system,
- pit blockage factors,
- existing pipe roughnesses and shapes, and
- the modelling of ponding of stormwater in streets and backyards.

In modelling existing systems, a difficult issue will be the definition of the flow paths taken by flows from paved and grassed surfaces, as shown in Figure 4.12. These will be greatly influenced by the size and arrangement of allotments and the buildings on them, and especially by the style of fencing along allotment boundaries.

If there was no fencing, or if flows could easily pass under fences, the flows would follow the land contours and the definition of paths and overland flow lengths, slopes and roughnesses would be relatively easy. Once flows have to pass through fences, or be directed along them, the situation becomes quite complex, with some storage effects probably coming into play. Even in a detailed analysis with abundant scope for survey data collection, it would be prohibitively expensive and complex to model each property's drainage system and to include possible storages. Some judgements about overall or average effects must therefore be made. Calibration with gauged data would be particularly useful for refining these judgements.

Another difficult issue will be the ponding of stormwater on streets and in backyards. This occurs where development has occurred in the natural floodway areas, and various barriers to flow have been erected, including road crowns, road embankments, walls and fences. It is fairly easy to see where stormwater will run into properties. Usually those on the downstream side of a road at a low point will be affected, as shown in Figure 4.13.

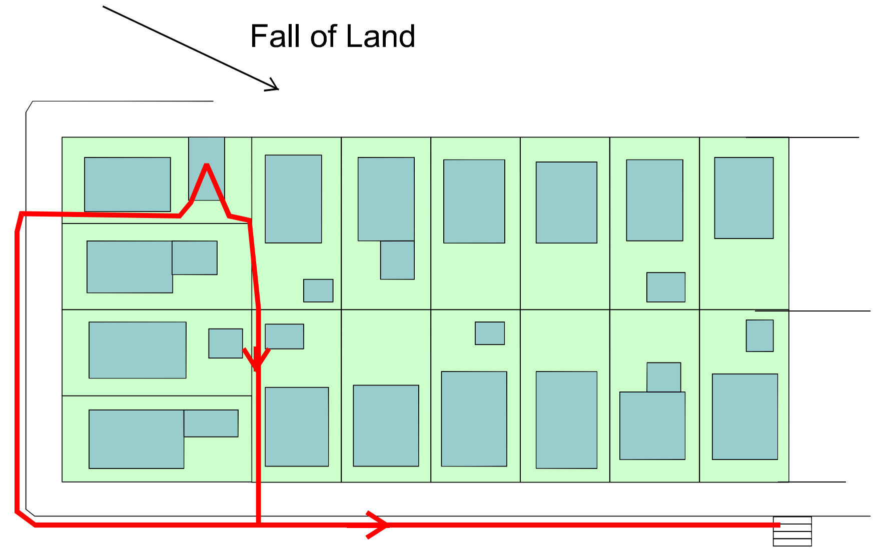


Figure 4.12 Flow Paths to a Pit

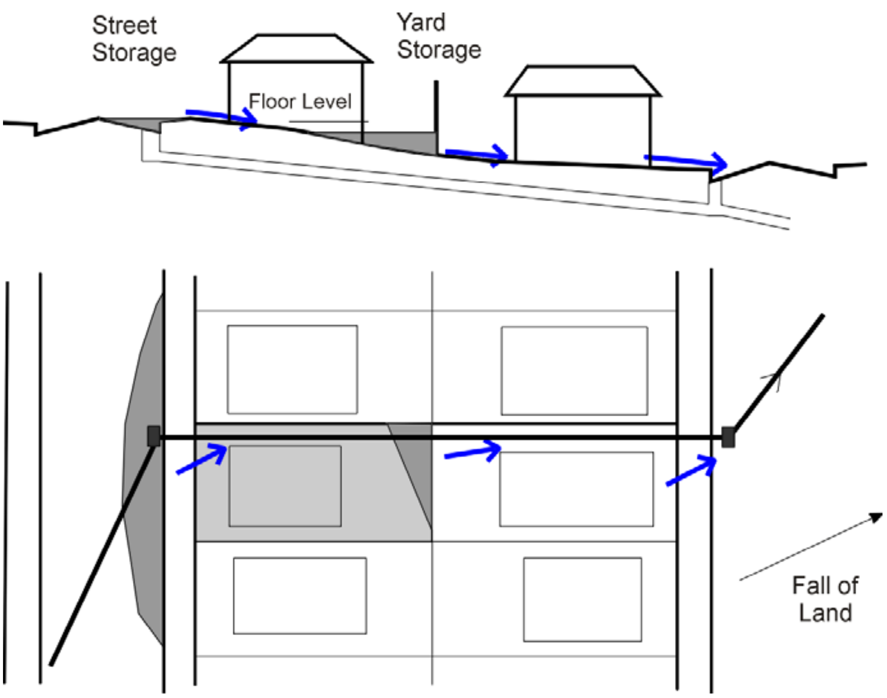


Figure 4.13 Ponding Storages on Streets and in Allotments

Storages on streets might be modelled as detention basins with a height-storage relationship and a low-level outlet to the pipe system. Their high level outlet or outlets can be modelled as one or more weirs, usually located a driveways into properties.

Storages within allotments can be very complicated, with flows being blocked by gates and fences, so that several instances of ponding may occur on the one property. Some situations can be modelled readily, such as flow under a fence represented as a sluice gate, or flow over a low wall as a weir flow. However, in many Australian situations, the barrier may be a metal Colorbond fence extending to the ground. Such fences can probably hold back stormwater to a depth of 1 m or more. When failure occurs, there may be catastrophic effects from the resulting rush of water and debris. Modelling such events is difficult. Our knowledge of how they are initiated is poor, and *DRAINS* does not model 'dambreaks' of this type.

Existing systems that have been augmented can have two pipes with different characteristics running more or less parallel. These might be modelled as multi-channels if there are no significant inflows along one of these that will change the distribution of flows. If this is the case, they can still be modelled as two

outlet pipes from a pit. *DRAINS* can model these using its full-pipe and open channel network calculation procedures.

The spreadsheet documentation provided by *DRAINS* is very useful for recording results, which can be separated into worksheets and suitably tagged.

When analysing very large systems (say 500 pipes and over) computation times can be quite long with multiple storms. It is therefore necessary to plan the analysis work, starting with storm events likely produce the highest flowrates. Once the system has been refined, final runs can be made with a wider range of rainfall patterns of different average recurrence intervals and durations.
Once a working model has been established, the likely flowrates, heights of storages, flooding impacts and resulting damages can be assessed. Flooding trouble spots can be identified, and remedial works can be considered. The initial *DRAINS* model can then be varied to produce a number of models for assessing different remedies. In some cases the remedies will interact with each other, some reinforcing the beneficial effects of other remedies, others diminishing these. This makes the consideration of options quite complex.

The rational method analysis procedure should not be used to simulate the behaviour of existing systems, since the various flow peaks calculated can occur at different times, and the flowrates obtained from combining peak flows are approximate. This procedure should only be used to check newly-designed systems. The extended rational method can be used as a valid analysis procedure, but the ILSAX hydrology is a more accurate and proved hydrological procedure.

Analyses should be carried out using the unsteady standard and premium hydraulic model calculations. These are superior to the basic hydraulic model in the following respects:

- They are more soundly based on theory, including all the terms of the St. Venant equations of mass and momentum conservation (see Section 5.6.4), so that they can model sub- and supercritical flows in pipes, channels, and with the premium hydraulic model, overflow routes
- They are more stable, and will give more accurate results for pipe and open channel flows.
- The premium model permits modelling of overflows and other configurations that are not possible in the basic model. (For example, it is possible to model two or more outflows from a sag or on-grade pit, or a node. Situations such as flows spilling from a street gutter or channel into a driveway or across a road centreline can be modelled in this way.)
- The premium model can model situations where on-grade pits are submerged by water ponding over adjacent sag pits, with the on-grade pit operating as a sag pit while it is submerged.
- The premium model provides greater allowance for storage in surface flow systems, such as ponded water over sag pits and surface flows between these, leading to generally lower flowrates.

With the availability of multi core processing, running times for the standard and premium models are faster than those for calculations with the older basic model. The basic model should only be used for checking older models, using the methods that applied when such models were developed.

4.3.5 Asset Management

Once developed and used to prepare construction plans and specifications, *DRAINS* models should be retained by the authority that maintains the system. Besides being a record of the system, with its own readily-accessible database, the *DRAINS* model is a working model of the system, which can be altered to reflect any changes. It can form part of the authority's asset management system, especially when it is integrated with drainage system data base and a geographic information system (GIS).

When the drainage system is constructed, it is likely that some details will have been changed during construction. The model should be updated to reflect the work-as-executed information. It will then require further modification as, whenever:

- additional drainage systems are connected,
- rezonings and re-developments create more impervious areas and increase runoff volumes and rates,
- possible flow diversions occur within the catchment, and between it and other catchments,
- compensatory detention storages are provided,
- additional information and experience about the drainage system accumulates,

- design rainfalls are revised, and climatic change effects occur,
- the system deteriorates and defects due to damage and ageing of assets become apparent,
- remedial works are constructed, and
- design standards change.

DRAINS can be easily updated to reflect all these changes. Periodic reviews can be made using the *DRAINS* model, which becomes a permanent feature of the drainage authority's asset management system.

Many municipalities and stormwater authorities do not have full information on their systems. Nevertheless, they can start with this incomplete data, setting up data bases and models with the available information, and then refining these. Experience during storm events special surveys to determine pit and pipe invert levels, CCTV inspections, preparation of lists of trouble spots and asset registers will provide added information, so the records can be gradually expanded and the modelling improved.

As shown in Figure 4.14, *DRAINS* provides transfers to GIS programs in the form of ArcView shapefiles and MapInfo MID/MIF files. The connection of *DRAINS* to the GISs of drainage authorities allows the results of *DRAINS* analyses to be included in the GIS. These can include flowrates and hydraulic grade line levels for average recurrence intervals of 1, 2, 5, 10, 20, 50 and 100 years, plus probable maximum precipitation (PMP) storms - see Bureau of Meteorology (2003). These results can be mapped and displayed in many ways, using colour-coded symbols and lines. The GIS can also act as a means of querying the underlying database, so that flows or HGL levels at particular locations can be checked on-screen.

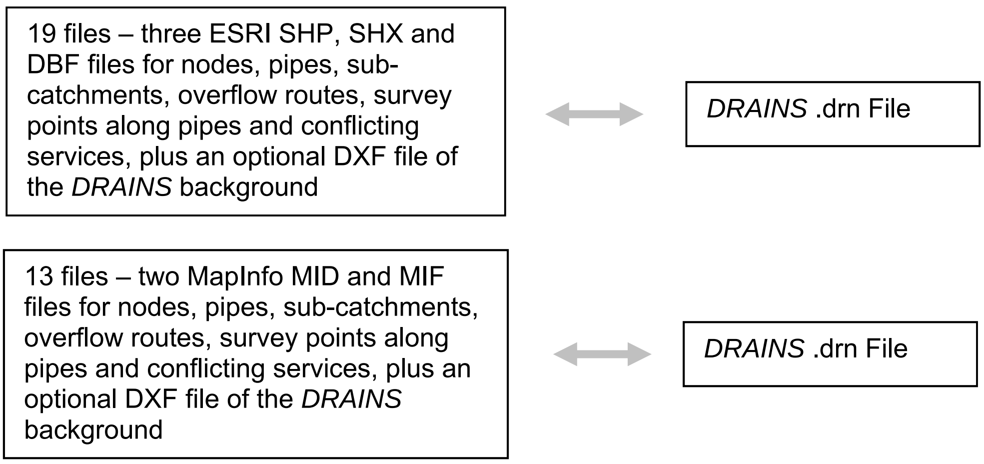


Figure 4.14 Transfers of Data Between *DRAINS* and GIS Programs

DRAINS does not export overflow routes as polylines, but as lines connecting the first and last points of the overflow route polyline. To display complex routes such as those passing through properties, it is recommended that these be represented by two or more segments joined at nodes.

Ultimately, drainage system managers can develop systems where revised *DRAINS* models can be created from information on previous *DRAINS* models in their GIS. As new developments and re-developments occur, it will be possible to include these. Results from various models can be retained in the GIS system. The combination of *DRAINS* with GIS allows managers to maintain and ongoing record of their drainage systems that included records of performance and flooding risk.

4.3.6 Performing Flood Studies with Storage Routing Models

The catchment must be defined on a contour map and sub-catchments defined using the stream pattern and the internal ridge lines as shown in Figure 4.15. The CatchmentSIM software (Ryan, 2005) can do this if suitable topographic information is available. Sub-catchment areas, channel reach lengths and other characteristics are then measured. The number of sub-areas should reflect the detail of the information required and the important features of the catchment, such as reservoirs and changes in the type of channel.

Streamflows and other data suitable for calibration of the model are then assembled. Ideally, there should be at least three recorded flood events. Loss parameters and initial values of the parameters (k_c in RORB, BX in RAFTS and C in WBNM) are established.

The program is then run and the outflows are compared with the calibration data, or rural catchment flood estimates developed by methods in Chapter 5 of *Australian Rainfall and Runoff* (Institution of Engineers, Australia, 1987). The parameters are then adjusted and the final calibration flowrates determined. If more than one storm event is available for calibration, it may require different parameters to obtain exact matches to recorded peak flows. A compromise set of parameters must then be selected.

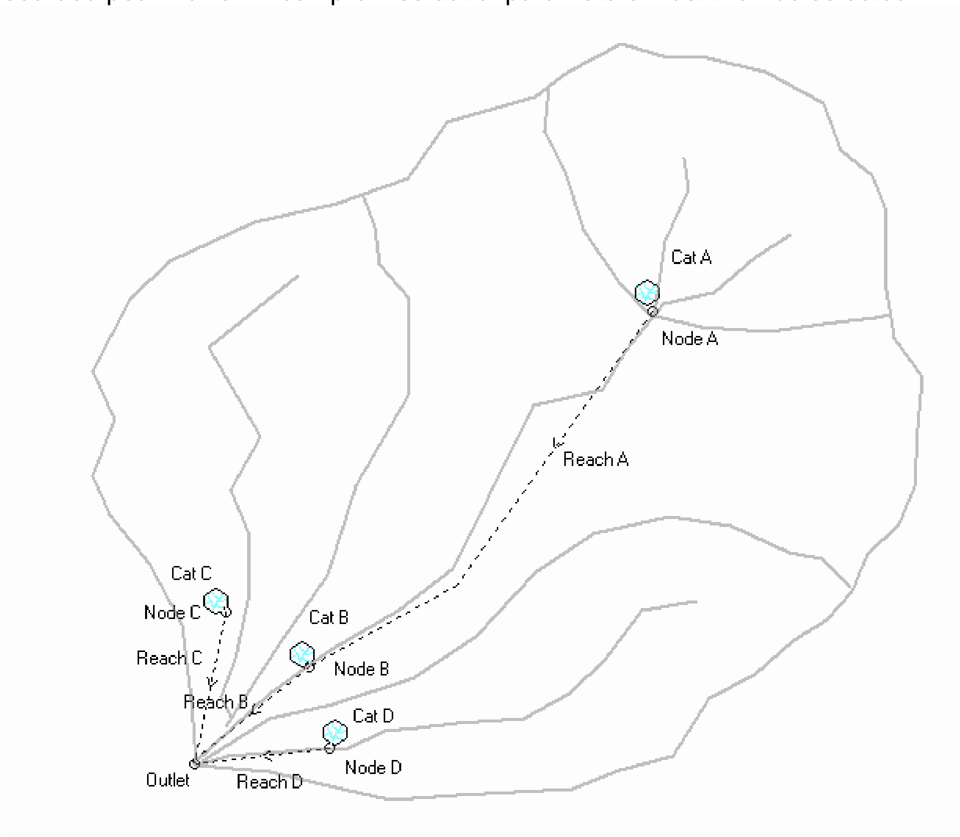


Figure 4.15 Layout of a RAFTS Storage Routing Model

With the parameters established, the model can be used to estimate the flows from large floods such as a 100 year ARI flood. The effects of detention basins and stream break-outs or diversions can be assessed.

If you wish to combine the storage routing model results with the open channel hydraulic calculations available in *DRAINS* and/or an ILSAX model, this can be done to obtain more detailed results. The open channel and ILSAX models can be set up in the usual way. This integration of models should be useful in situations where there is interaction between a large watershed and a smaller urban catchment.

4.3.7 Methods and Parameters Applied in *DRAINS*

Usually, designers must follow guidelines established by drainage consent authorities, such as local councils or state road authorities, supplemented by authoritative guides such as *Australian Rainfall and Runoff*, the *Queensland Urban Drainage Manual* or *AS/NZS 3500.3*. Nevertheless, there will be many situations that are not covered completely in these sources. It is the responsibility of the designer to choose how these situations are to be modelled and what parameters are to be applied.

DRAINS is a flexible tool that can be used with many different procedures and parameters, and it is inappropriate for this manual to recommend specific methods or values, or to specify how *DRAINS* should be applied in specific situations. There is a discussion of alternative hydrological models in Appendix A.

4.3.8 Choice of Model

DRAINS offers a choice of hydrological and hydraulic models. Some are available to all purchasers, while others can be purchased as optional add-ons. The choice of hydrological model will depend on the task to be undertaken with the model, and by the likelihood of acceptance of the model by approval

authorities or assessors. Comparisons of alternative models are presented in the guidance on the *DRAINS* Viewer that is included in Appendix A.

All hydrological models except the rational model produce hydrographs, which are necessary for modelling detention storages and complex networks. The ILSAX and storage routing models (RORB, RAFTS and WBNM) are backed by testing programs in which their performance has been tested against gauged rainfall and runoff data. The rational method models have not been extensively tested, but have been the most commonly-used models in many applications. Some authorities consider them to be acceptable benchmarks. The extended rational model included in *DRAINS* is an extension of the rational method.

The storage routing models are the accepted methods of modelling broad-scale urban catchments and can cope with the hydrological effects of urbanisation. The various models produce different flow estimates due to (a) use of different rainfall data, notable I-F-D statistical relationships and Australian *Rainfall and Runoff* patterns, (b) models being derived for different purposes, scales of operation (pipe system sub-catchments compared to larger broad-area sub-catchments), and calibration to different data sets, and (c) modelling choices by users. (Some models allow users much more scope than others.)

For routine applications such as OSD calculations, designers probably should choose models accepted by approval authorities, while for more complex or critical applications, the more scientifically-proven and calibrated models will be the ones that can best model situations and be most easily justified.

The basic hydraulic model that was used from the first release of *DRAINS* has been replaced by the standard and premium hydraulic models, which are based on different principles and are more rigorous and stable. Because both of these models allow for volumetric effects in stored and flowing runoff, they calculate lower flowrates than the old basic hydraulic model, with the premium model usually giving the lowest flowrates and HGL levels.

5. TECHNICAL REFERENCE

5.1 Introduction

This chapter sets out the background and the technical basis for the procedures used in *DRAINS*. Some features, such as the ILSAX hydrological model, were inherited from other programs while others were developed specially for *DRAINS*.

5.2 Predecessors

DRAINS is the result of a chain of development that originated with the U.K. Transport and Road Research Laboratory (TRRL) Method in the early 1960s:

TRRL Method (UK, 1962)
⇓
ILLUDAS (US, 1974)
⇓
ILLUDAS-SA (South Africa, 1981)
⇓
ILSAX (Australia, 1986)
⇓
PIPES++ ⇒ ***DRAINS*** (Australia, 1998)

Figure 5.1 The Initial Development Path of *DRAINS*

The TRRL method was developed by Watkins (1962) following extensive studies in which storm rainfalls and runoff were recorded for several years on twelve catchments. Flow estimates from the rational method and other hydrological models were compared with the recorded data. A design procedure using the time-area method (Ross, 1921) applied to impervious areas was developed from this research (UK Transport and Road Research Laboratory, 1976). A simple procedure was applied to route flows through pipe systems. This was released as a FORTRAN program in 1963, replacing the rational method.

The Illinois Urban Drainage Area Simulator, ILLUDAS, was developed and extensively tested by Terstriep and Stall (1974), who adapted the TRRL Method to cope with pervious area runoff and added other features. Tests involving gauged data from 21 catchments were made. Although ILLUDAS was popular among researchers, it has not been widely used by designers in North America. For most design tasks, ILLUDAS and SWMM (Stormwater Management Model) have been overshadowed by U.S. Soil Conservation Service programs TR20 and TR55 and other, relatively-simple methods.

After testing ILLUDAS on two South African gauged catchments, Watson (1981) produced a version named ILLUDAS-SA, with many additional features. This was the basis for the ILSAX program. In Australia, ILLUDAS-SA and various development versions of ILSAX were applied to data from gauged urban catchments in Sydney and Melbourne by Cartwright (1983), Mein and O'Loughlin (1985), Vale, Attwater and O'Loughlin (1986), and others. The first practical application was in a large-scale drainage study of Keswick and Brownhill Creeks in suburban Adelaide in 1982-83.

ILSAX was developed by Geoffrey O'Loughlin between 1982 and 1986, with the aim of producing a better stormwater drainage design program than the rational method. The later part of this development occurred alongside the preparation of the chapter on urban stormwater drainage in *Australian Rainfall and Runoff*, 1987. ILLUDAS-SA was adapted to model overflows from pits, so that it could model major storm flows in the major/minor design system recommended in *Australian Rainfall and Runoff*. However, the program did not calculate HGLs. ILSAX started to be used widely in 1986, when it was released in a public domain version for IBM PCs. Its flexibility, low cost and robustness made it acceptable, despite the limitations of its hydraulic calculation method. The early testing showed that the hydrological model was at least as accurate as alternative urban hydrology models. In the 1990s, it was commonly used for analysis of on-site stormwater detention systems. It has now been superseded by *DRAINS* and is no longer supported.

PIPES and PIPES++ are hydraulic network analysis programs developed in the 1990s by Bob Stack for the design and analysis of piped water supply systems. Full pipe flows were modelled using steady flow

equations, and a graphical user interface was provided, which became the bases for the interface in *DRAINS*.

5.2.1 *DRAINS*

DRAINS grew out of attempts by Geoffrey O'Loughlin to provide a successor program to ILSAX. A joint venture with Bob Stack of Watercom Pty Ltd yielded a program that combines an effective user interface from Watercom's PIPES programs with the ILSAX model and a much-improved pipe and channel hydraulics system. Development took place from 1994 to 1997, and has continued to the present time, with important developments being shown in Table 5.1.

Table 5.1 Significant Developments in the Capabilities of *DRAINS*

Date	**Development**
1993-1997	Development of *DRAINS* from ILSAX and PIPES with HGL projection procedures for pipes and open channels
January 1998	Commercial release of *DRAINS*
Early 1998	Addition of pressurised models to allow for sealed pits
1999	Addition of spreadsheet input-output
1999	Introduction of rational method procedures,
2001	Introduction of the Advanced Design Method (with new pipe, pit and overflow route data bases)
2002	Introduction of storage routing models emulating procedures in the RORB, RAFTS and WBNM programs
Early 2003	Allowance for looped pipe systems
Mid 2003	Introduction of transfers to and from GIS programs
Late 2004	Addition of the extended rational method
Mid 2005	Addition of HEC22 procedures for calculation pit inlet capacities
March 2006	Introduction of fully dynamic (unsteady) calculations for pipes, open channels and overflow routes
2007	Use of *DRAINS* Utility Spreadsheet to prepare input data externally.
February 2008	Introduction of Queensland Urban Drainage Manual (QUDM) procedures for automatically determining pit pressure change coefficients.
March 2009	Release of the free *DRAINS* Viewer
December 2010	Replacement of the basic hydraulic model by the standard and premium models. Parallel processing introduced to greatly reduce run times.
2012	Multiple rainfall pattern entry, New orifice and weir components
2012-14	Enhancements to unsteady flow calculations, improving speed and stability.
2014	Enhanced pipe system design procedure.

The rational method, the extended rational method and storage routing models have been added to the original ILSAX hydrological model. The basic hydraulic model, which underwent considerable development between 1989 and 2010, has now been replaced by unsteady flow models.

5.3 Hydrology

5.3.1 General

Simulation models such *DRAINS* require a model to transform rainfall patterns to runoff hydrographs in the part of the hydrological cycle shown in Figure 5.2.

Urban stormwater drainage design can be carried out by three categories of models:

(a) simple models that produce a peak flow estimate only (such as the rational method),

(b) hydrograph-producing models (such as the time-area model in ILSAX) applied to storm events, and

(c) more complex models, capable of continuous simulation of hydrographs (such as the Stormwater Management Model, SWMM).

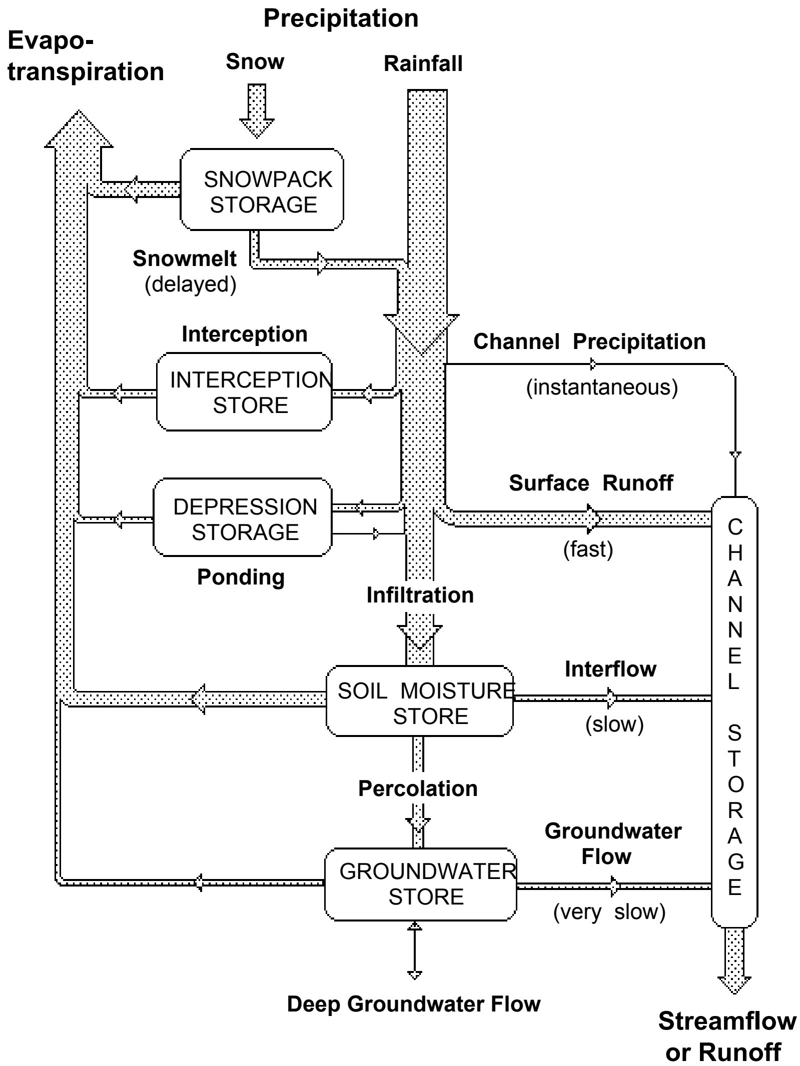


Figure 5.2 The Rainfall-Runoff Process

Models can be split into loss models and routing models, as shown in Figure 5.3. Loss models represent hydrological processes such as interception, depression storage, evaporation and infiltration, which prevent water from running off catchments immediately. The most common types are: (a) initial loss – continuing loss models, and (b) infiltration models using procedures such as Horton's equation.

Routing models allow for the distribution of rainfall across a catchment surface, with some rainfall inputs being closer to the outlet than others, and so spreading out the pattern of flow or hydrograph at the outlet. They also account for storage effects on the catchment. The main types are (a) time-area routing, (b) unit hydrographs, (c) routing through artificial storages, (d) kinematic wave routing, and (e) unsteady flow hydraulic modelling across catchment surfaces.

The ILSAX hydrological model in *DRAINS* is a medium-level rainfall-runoff model that combines a Horton loss model with time-area routing. The rational method only calculates peak flowrates. The ERM applies a loss model based on the rational method with time-area routing. These models are adaptable to many situations, but do not perform continuous simulation. The storage routing models that emulate the RORB, RAFTS and WBNM models commonly used in Australia are also 'event models', designed to produce hydrographs for flood estimation, but not capable of modelling long periods of runoff under wet and dry conditions.

5.3.2 The ILSAX Hydrological Model

(a) General Description

This model relates to an urban or semi-urban catchment, subdivided into sub-catchments linked to a drainage system of pipe and channel sections as shown in Figure 5.4. Sub-catchments are divided into three surface types - paved, supplementary and grassed. Runoff hydrographs generated from inputted

rainfall patterns are used to model system behaviour and to perform design tasks. The model works to a fixed time scale, beginning at the start of a storm, performing calculations at specified time steps.

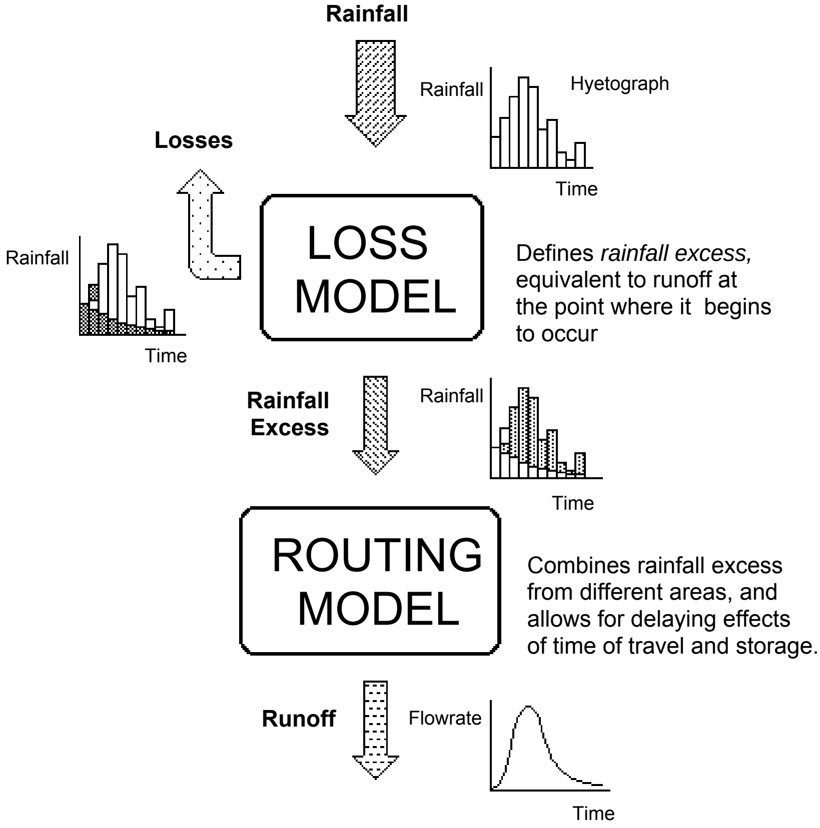


Figure 5.3 Loss and Routing Models

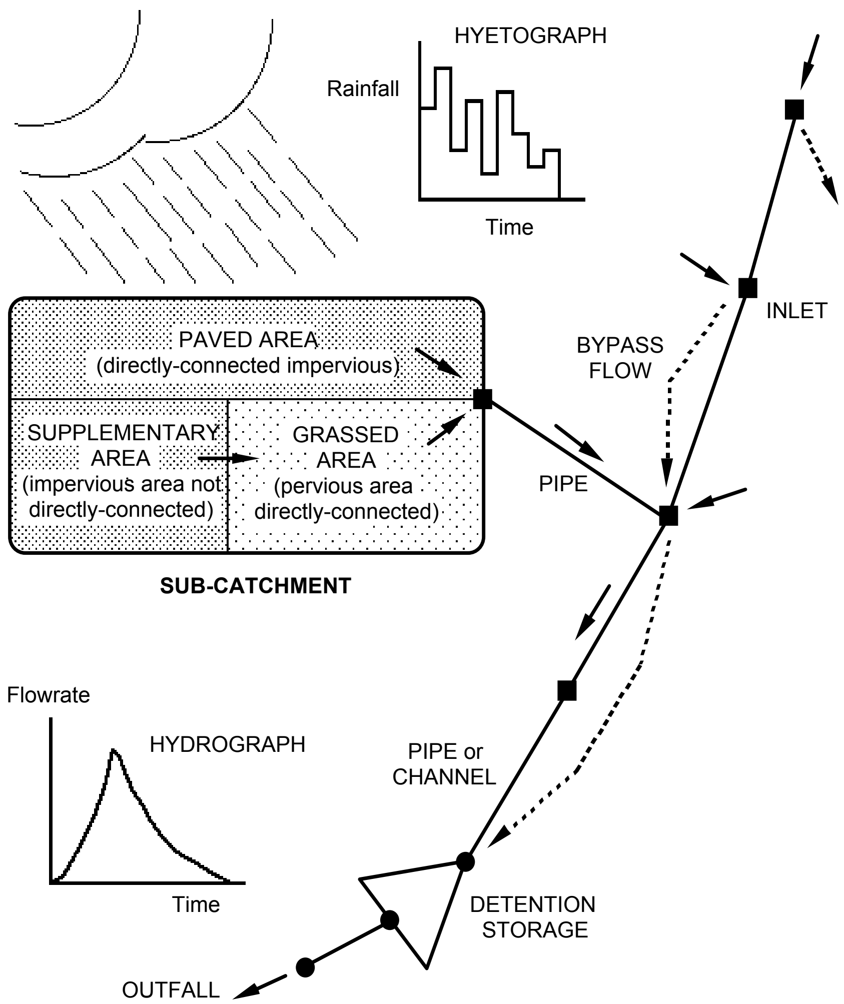


Figure 5.4 The Layout of the ILSAX Model

Since this is an event model, conditions at the start of each storm event must be established by defining a value of the antecedent moisture condition, AMC, for the soil underlying the pervious portions of the catchment. The loss model subtracts depression storages from all surfaces and calculates additional losses for grassed or pervious areas using Horton's infiltration model. The soil type and AMC parameters are easily understandable and can be related to identifiable soils and rainfall depths preceding a storm. Results are quite sensitive to the AMC and users must consider the effects of their choices using sensitivity studies. Despite this, few problems with employing this model have been reported.

The model relies on times of travel as the main parameters used in routing. These can be determined to an acceptable level of accuracy for urban catchments, but are very variable for rural catchments. Thus, while the ILSAX model can be applied to pervious sub-catchments of a drainage system, it is not strictly applicable to rural catchments. This reflects the lack of suitable studies to calibrate the model in rural conditions, rather than any defect in the model itself.

(b) Time-Area Routing

The basis of the ILSAX model's hydrograph generation is the time-area method, illustrated in Figure 5.5, which 'convolves' the rainfall hyetograph with a time-area diagram, in a similar manner to unit hydrograph calculations. A time of entry (or time of concentration) must be determined for a drained area using methods discussed later in Section (d).

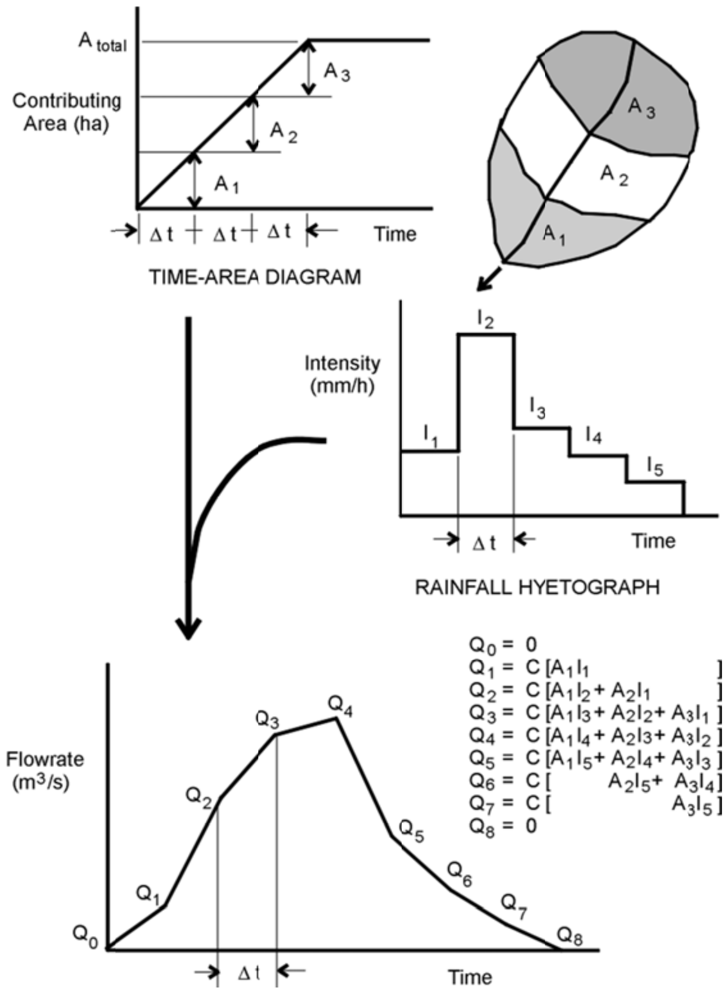


Figure 5.5 Time-Area Calculations

Assume that the rainfall hyetograph has had losses removed and so represents rainfall excess, and that the hyetograph is divided into time steps of Δt. The time-area diagram, a plot of the catchment area contributing after a given number of time steps is divided in the same intervals. This diagram can be visualised by drawing isochrones, or lines of equal time of travel to the catchment outlet. For times greater than the time of concentration, the contributing area equals the total area of the catchment.

When a storm commences on a catchment that has a time of entry of $5\Delta t$, the initial flow Q_0 is zero. After one time step Δt, only sub-area A1 contributes to the flow at the outlet. Any runoff from other sub-areas is

still in transit to the outlet. Thus the flowrate at the end of the first time step can be approximated by $Q_1 = c.A_1 . I_1$, where c represents the conversion factor from mm/h to m^3/s units, and I1 is the average rainfall intensity during the first time step.

At the end of the second time step, there are two contributions to the outlet flow, Q_2, due to the second block of rainfall falling on the sub-area nearest to the outlet, $c. A_1 .I_2$, and to runoff from the first rainfall block on the second sub-area, $c. A_2 . I_1$. At the end of the third time step, there are three contributions, $Q_3 = c. (A_1 . I_3 + A_2 . I_2 + A_3 . I_1)$, and so the process continues, as shown in Figure 5.5. The hydrograph builds up to a peak and then recedes once rainfall stops and the catchment drains.

In practice, losses can be subtracted from the rainfalls and flows before or after these time-area calculations are made. The latter choice is recommended for grassed or paved areas, as this allows infiltration to occur from flows moving across a sub-catchment after rainfall has stopped. In this case, the hydrograph of Q values represents a 'supply rate', from which losses must be subtracted later.

In *DRAINS*, as in ILSAX, it is assumed that all time-area diagrams are straight-lines. It is conceivable that they could be concave or convex, depending on catchment shape on other factors, however, investigations conducted in the U.K. with the TRRL Method concluded that this degree of accuracy was not necessary.

(c) Catchment Surface Types

The sub-catchments draining to each entry point on the pipe and channel system can be obtained from maps, aerial photographs and GIS information, as well as field inspections. The likely effects of fences along property boundaries and other barriers must be assessed.

In the ILSAX model used in *DRAINS*, each sub-catchment must be divided into the sub-areas shown in Figure 5.6, with the following surface and drainage characteristics:

- paved areas, impervious areas directly connected to the pipe system, including road surfaces, driveways, roofs connected to street gutters, etc.,
- supplementary areas, impervious areas not directly connected to the pipe system, but draining onto pervious surfaces which connect to this system (These may include tennis courts surrounded by lawns, house roofs draining onto pervious ground, etc. distributed evenly next to the grassed area.), and
- grassed areas, pervious areas directly connected to the pipe system, including bare ground and porous pavements as well as lawns.

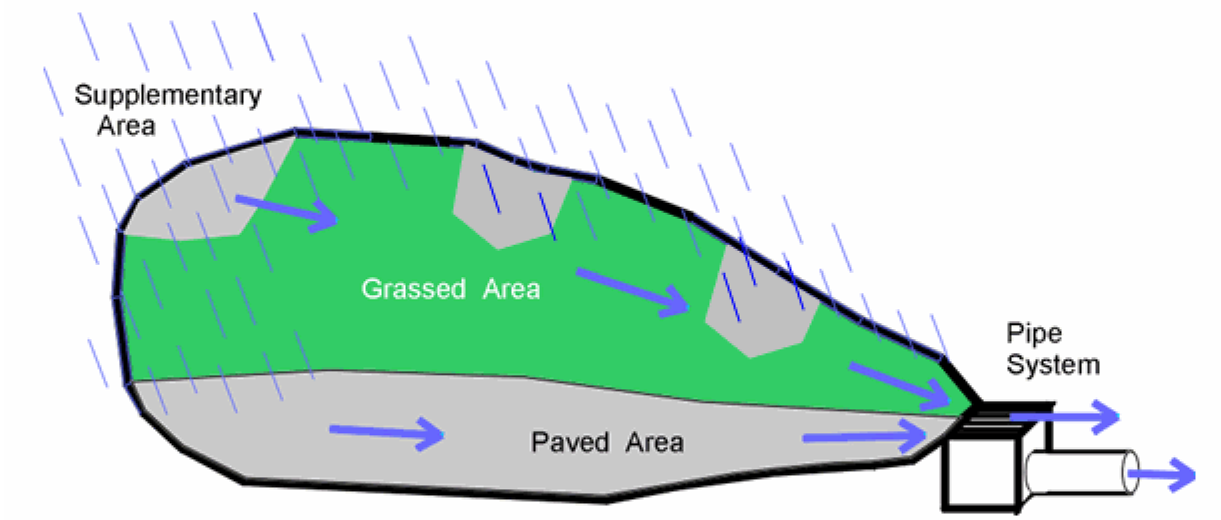


Figure 5.6 ILSAX Model Surface Types

In *DRAINS*, the total sub-catchment area and the percentages of paved, supplementary and grassed areas must be specified for each sub-catchment. If there is some part of a sub-catchment that does not drain to the drainage system, for example, a hollow or depression in volcanic areas, it should be excluded from the model.

Generally, fully-developed medium density residential catchments will have areas impervious between 30 and 70%. Dayaratne (2000) has obtained the following relationships from modelling of storms on 16 gauged residential catchments in four Victorian municipalities:

Directly connected impervious area (or paved area) percentage,

$$\text{DCIA } (\%) = -0.85 \text{ hhd}^2 + 23.38 \text{ hhd} - 101.19 \quad (r^2 = 0.90) \qquad \text{… (Equation 5.1)}$$

Supplementary area percentage,

$$\text{SA } (\%) = -0.04 \text{ hhd}^2 + 1.13 \text{ hhd} - 3.79 \quad (r^2 = 0.91) \qquad \text{… (Equation 5.2)}$$

where hhd is the number of houses/ha.

These equations produce the numbers shown in **Table 5.2**.

Table 5.2 Estimates Paved and Supplementary Area Percentages

Housing Density, hhd (houses/ha)	**Paved Area**, DCIA (%)	**Supplementary Area** (%)
6	8.5	1.5
7	21	2.2
8	31	2.78
9	40	3.1
10	48	3.5
11	53	3.8
12	57	4.0
13	59	4.1
14	60	4.2

As noted in connection with Figure 2.16, supplementary areas may be used to model systems where roofwater is discharged onto grassed areas.

(d) Overland Flows and Times of Entry

Times of entry must be specified for the paved and grassed areas (and also for the supplementary area in *DRAINS*). These are effectively the same as the times of concentration or times of travel used in the rational method. They set the base lengths of the time-area diagrams used to create hydrographs.

The *DRAINS* property sheet for a sub-catchment is shown in Figure 5.7. Information on surface types is arranged in three columns. The length of these varies according to the level of detail selected in the **Use** box. For many applications, fixed times can be entered.

However, it is also possible to calculate a time by the steady-state 'kinematic wave' equation for overland flows (Ragan and Duru, 1972):

$$t_{overland} = 6.94 \, . \, \frac{(L \cdot n^*)^{0.6}}{I^{0.4} \cdot S^{0.3}} \qquad \text{…(Equation 5.3)}$$

where time $t_{overland}$ is in minutes, flow path length L is in m, rainfall intensity I is in mm/h and slope S is in m/m.

The surface roughness n* is similar to the coefficient n in Manning's Formula for open channel flows, but is of a different magnitude. It typically takes the values set out in Table 5.3. Values for lawns and grassed surfaces show considerable variation, depending on the depth of flow relative to the height of grass blades. Values from 0.05 to 1.0 have been obtained by various researchers, as described by Engman (1986).

In *DRAINS*, intensity I is taken as the mean intensity of the rainfall pattern supplied. This should be satisfactory for design rainfall bursts such as those supplied in *Australian Rainfall and Runoff*, 1987, but may be erroneous for some more variable or patchy patterns that occur naturally.

For paved areas, it is also possible to calculate a gutter flow time using (a) an equation for flows in street gutters or channels (U.S. Federal Highway Administration, 1984) , (b) Manning's equation, or (c) more simply, by dividing a flow path length by a speed to obtain a time.

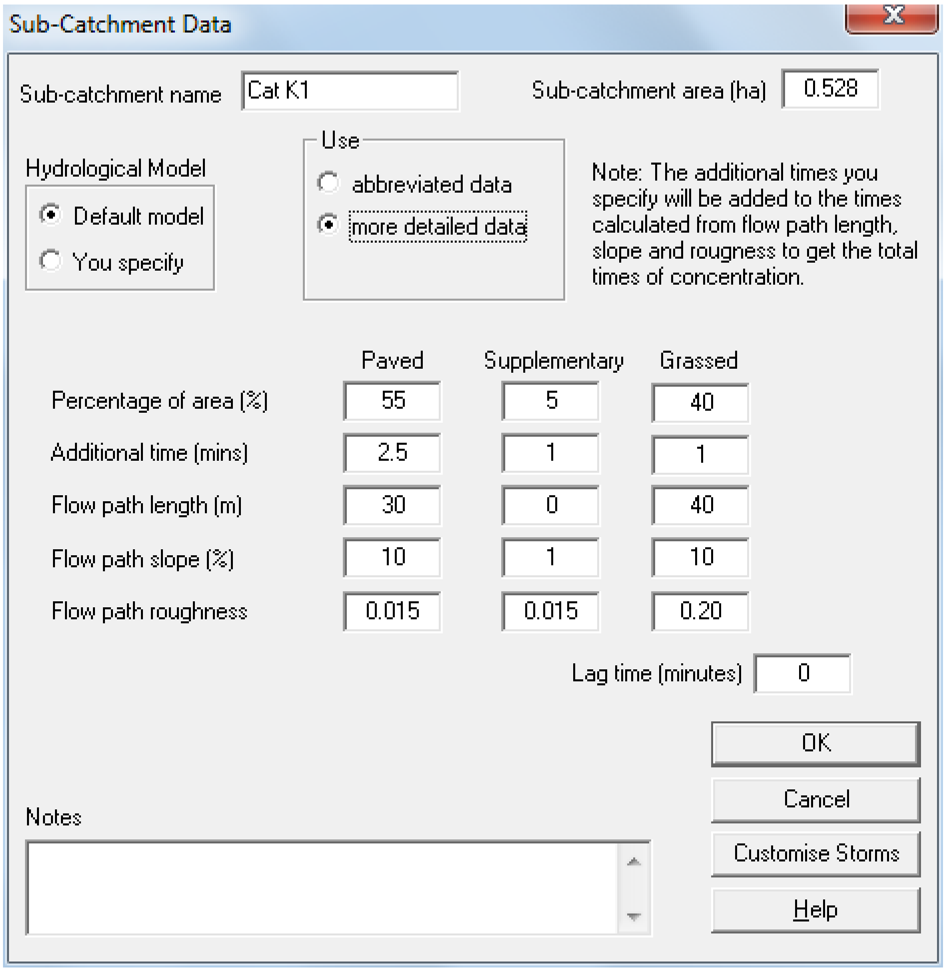


Figure 5.7 Sub-Catchment Property Sheet with Text Boxes for Entry of Data

Table 5.3 Surface Roughness Factors

Surface Type	Roughness Coefficient n
Concrete or Asphalt	0.010 - 0.013
Bare Sand	0.010 - 0.016
Gravelled Surface	0.012 - 0.030
Bare Clay-Loam Soil (eroded)	0.012 - 0.033
Sparse Vegetation	0.053 - 0.130
Short Grass Prairie (Veldt or Scrub)	0.100 - 0.200
Lawns	0.170 - 0.480

[Source: Woolhiser (1975)]

In *DRAINS*, a kinematic wave flow time can be added to a constant time, as follows:

Total time = Constant time, which can represent property drainage time plus gutter flow time
+ Overland flow time calculated from length, slope and roughness … (Equation 5.4)

Users can specify the times associated with paved, supplementary and grassed areas as (a) a constant time, (b) a constant time, now called an 'additional' time, plus a kinematic wave calculation, or (c) a kinematic wave time only, by specifying the additional time as zero. Up to 2005, there was a third term that modelled street gutter flow times using equations based on road cross-sections. This has been omitted in the current version of *DRAINS* but may appear in older models. It is described in the *DRAINS* Help system.

The property drainage time is that required for all water to contribute to flow at the boundary outlet. There is conflicting evidence on property drainage times (Stephens and Kuczera, 1999, Goyen and O'Loughlin, 1999, Dayaratne, 2000), with some pointing to short times, 1 or 2 minutes, and some to longer times, 5 to 10 minutes). 1 to 2 minutes is recommended as being reasonably conservative.
In *DRAINS*, a lag time for grassed area flows can be applied where flows from such areas pass over paved surfaces before reaching a pit, as shown in the lower part of Figure 5.8. The time to be entered is the flow time over the paved area.

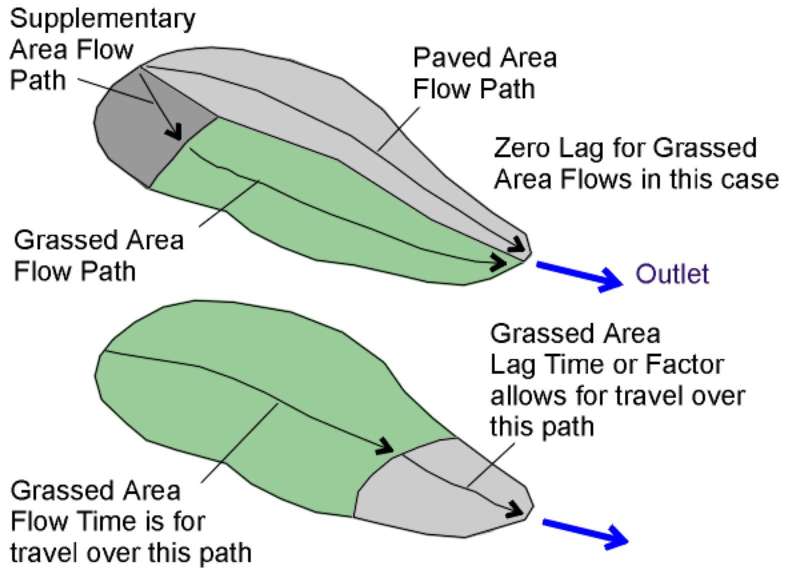


Figure 5.8 Lag Times and Factors

The *Queensland Urban Drainage Manual*, QUDM (2008) recommends a simplified procedure for setting inlet times, using the values in Table 5.4. Should the calculated t_c be less than 5 minutes, this minimum value is customarily adopted as the t_c.

Table 5.4 Recommended Standard Inlet Times in Queensland Urban Drainage Manual

Location	**Inlet Time** (minutes)
Road surfaces and paved areas	5
Urban and residential areas where:	
- average land slope is greater than 15%	5
- average land slope is between 10% and 15%	8
- average land slope is between 6% and 10%	10
- average land slope is between 3% and 6%	13
- average land slope is up to 3%	15

(e) ILSAX Loss Models

Losses from paved and supplementary areas are calculated simply in the ILSAX model. Depression storages are considered as initial losses subtracted from rainfall hyetographs prior to time-area calculations. The general range of depression storages is from 0 to 2 mm for impervious surfaces and 2 to 10 mm for pervious surfaces. Commonly-used values for paved, supplementary and grassed areas are 1, 1 and 5 mm, respectively. Dayaratne (2000) recommends values of 0 to 1 mm for impervious areas.

The procedures for grassed areas are more complex. They are based on the general equation developed by Horton in the 1930s:

$$f = f_c + (f_0 - f_c) \cdot e^{-kt} \qquad \text{… (Equation 5.5)}$$

where f is infiltration capacity (mm/h),
f_0 and f_c are initial and final rates on the curve (constants, mm/h),
k is a shape factor, here taken as 2 h^{-1},
and t is the time from the start of rainfall (minutes).

This describes the curves shown in Figure 5.9. These only apply when there is sufficient rainfall to satisfy completely the infiltration capacities, and accumulated infiltration is increasing at its full rate.

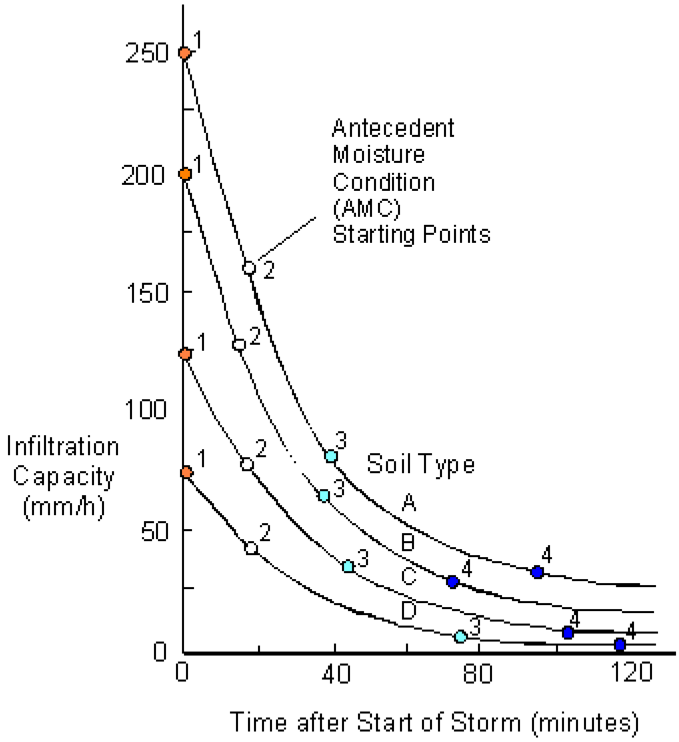


Figure 5.9 Horton Infiltration Curves

The curves represent soil types which follow the classification used by Terstriep and Stall (1974), based on the system developed by the U.S. Department of Agriculture, and described in references such as Chow (1964) and U.S. Natural Resources Conservation Service (2007). These are used in North American procedures such as Technical Release 55 of the U.S. Soil Conservation Service (1975). The four main soil classifications, designated A, B, C and D (corresponding to 1, 2, 3 and 4 in the ILSAX type model), are described as:

1 (or A) - low runoff potential, high infiltration rates (consists of sand and gravel);

2 (or B) - moderate infiltration rates and moderately well-drained;

3 (or C) - slow infiltration rates (may have layers that impede downward movement of water);

4 (or D) - high runoff potential, very slow infiltration rates (consists of clays with a permanent high water table and a high swelling potential).

These soil types are used in conjunction with antecedent moisture conditions (AMCs) that define the points on the infiltration curves at which calculations commence. This is specified, not by an initial infiltration rate in mm/h, but by an antecedent depth of moisture, corresponding to the area under the curve to the left of the starting point. On each curve in the above figure, four starting points (numbered 1, 2, 3 and 4) are shown, representing possible AMCs.

AMCs can be estimated from Table 5.5. Both soil types and AMCs can be interpolated between the levels of 1, 2, 3 and 4.

Table 5.5 Antecedent Moisture Conditions

Number	**Description**	**Total rainfall in 5 days preceding the storm** (mm)
1	Completely dry	0
2	Rather dry	0 to 12.5
3	Rather wet	12.5 to 25
4	Saturated	Over 25

For the curve and AMC selected, the model calculates an infiltration loss in each time step. This is subtracted from the rainfall inputs to the pervious area.

Values of parameters involved with various combinations of soil types and AMCs are set out in Table 5.6.

Table 5.6 Infiltration Model Parameters

Factor	Soil Type			
	A (or 1)	B (or 2)	C (or 3)	D (or 4)
Initial Rate, f_0 (mm/h)	250	200	125	75
Final Rate, f_c (mm/h)	25	13	6	3
Shape Factor, k (h^{-1})	2	2	2	2
Antecedent Rainfall Depths (mm) for AMCs:				
1	0	0	0	0
2	50	38	25	18
3	100	75	50	38
4	150	100	75	50
Initial Infiltration Rates (mm/h) for AMCs:				
1	250	200	125	75
2	162.3	130.1	78.0	40.9
3	83.6	66.3	33.7	7.4
4	33.1	30.7	6.6	3.0

Users also can also provide their own values. One method to do this is to analyse daily rainfall records and on a spreadsheet calculate the rainfalls for the 5 days preceding each day. Daily rainfalls can then be ranked and the antecedent rainfalls for the highest 100 rainfalls, say, can be analysed, as shown in Figure 5.10 which gives results for Observatory Hill rainfall records in Sydney. From the mean or median antecedent rainfalls and classification numbers, a most-likely value of AMC can be selected.

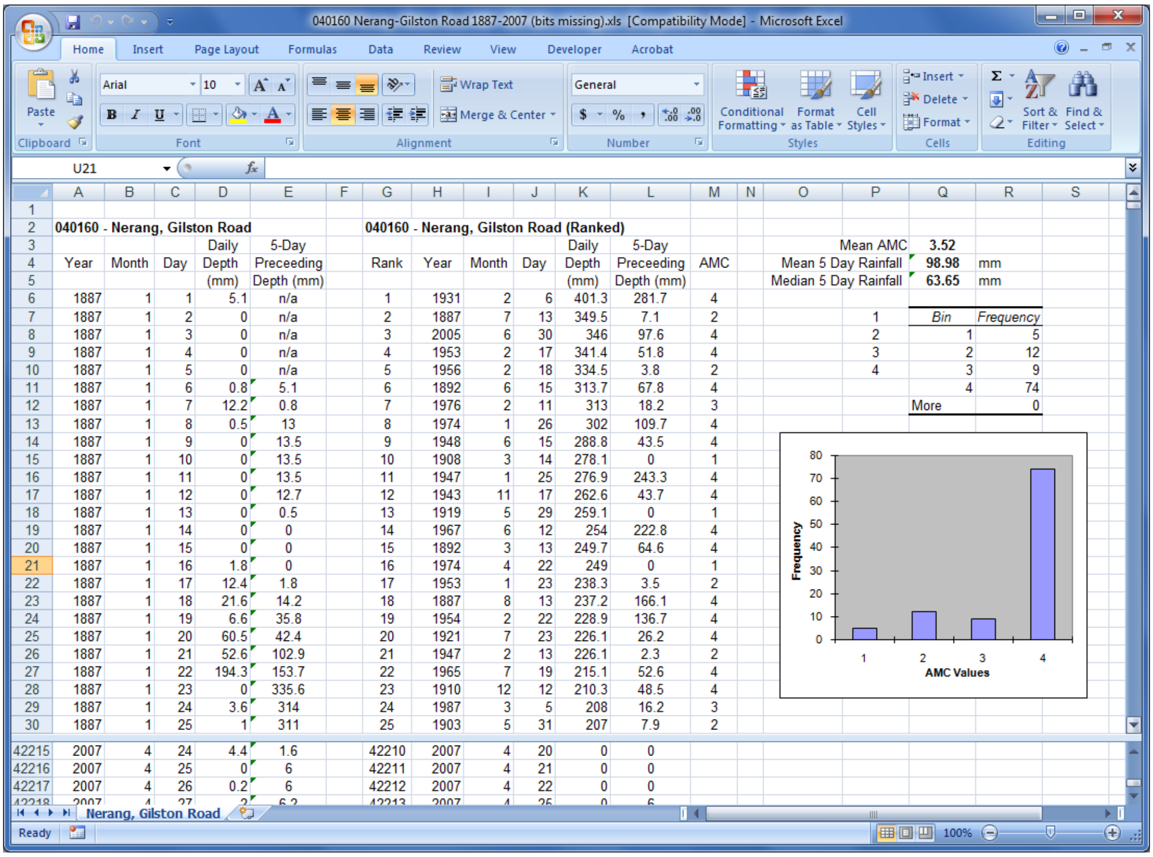


Figure 5.10 Procedure for Determining AMCs for Design Purposes from Daily Rainfalls

This classification involving soil type and AMC has been found to give good fits to recorded storm hydrographs from gauged catchments in Australia, and the soil types have been accepted by ILSAX and *DRAINS* users. Siriwardena, Cheung and Perera (2003) compared the infiltration rates in Table 6.4 with those measured with infiltrometers at eight urban gauged catchments in Victoria. They found that the f_0 and f_c values measured were generally higher than those for the same soil classification in Table 5.6. They obtained f_0 values of 28 to 503 mm/h compared to 13 mm/h for a Type B soil, and f_c values of 4 to 135 mm/h, compared to values of 31 to 200 mm/h. They also obtained a shape factor, k, of 0.85 h^{-1} compared to 2 h^{-1} in the table.

Siriwardena, Cheung and Perera did not explore the implications of changing these parameters in modelling hydrographs from the test catchments. It is not possible to assess the effects of this at present, but Victorian users of *DRAINS* and similar programs should take the above results into consideration when setting parameters. *DRAINS* s allows user-provided parameter values to be specified in the hydrological model inputs.

In ILLUDAS-SA and ILSAX, the following form of Horton's equation was used to determine the infiltration rate from the accumulated depth of infiltration. This allows for variable rainfall intensities that might be less than the infiltration capacities at some times.

$$f \;=\; f \;+\; fc\,.\left(1 - \frac{f}{f_c + (f_0 - f_c).e^{(f_0 - kF - f)/f_c}}\right) \qquad \text{... (Equation 5.6)}$$

where f is the current infiltration capacity (mm/h), and
F is accumulated depth of infiltration (mm).

The infiltration rate calculated from this is subtracted from the hyetograph or supply rate, and should any water remain, depression storage is subtracted. Once the depression storage has been fully satisfied, any excess over infiltration is assumed to be runoff. The accumulated infiltration depth is increased by the amount assumed to be infiltrated. For porous soils and light rainfalls, it is quite possible that there will be zero runoff from pervious surfaces.

Malcolm Watson, the developer of ILLUDAS-SA, suggested that an alternative method could be used which would not involve iterative calculations, and this was incorporated into ILSAX. This procedure, described by Watson (1981b), involved the division of the infiltration curve equation into diminishing and constant components $(f_0 - f_c)\,.\,e^{-kt}$ and f_c. Watson used this concept in the following analysis:
The actual depth of infiltration, ΔF, over time step Δt is the lesser of $I\,.\,\Delta t$, where I is rainfall intensity, and

$$F_{cap} \;=\; (1 - e^{-k\Delta t})\,.\left(\frac{(f_0 - f_c)}{k} - F_d\right) + f_c\,.\,\Delta t \qquad \text{… (Equation 5.7)}$$

where F_d is the accumulated diminishing infiltration, determined at each time step by

$$F_d \;=\; F_d \;-\; \frac{\Delta F}{\Delta F_{cap}}\,.\,(\Delta F_{cap} - fc.\,\Delta t) \qquad \text{… (Equation 5.8)}$$

which apportions actual infiltration depths between diminishing and constant components, as shown in Figure 5.11.

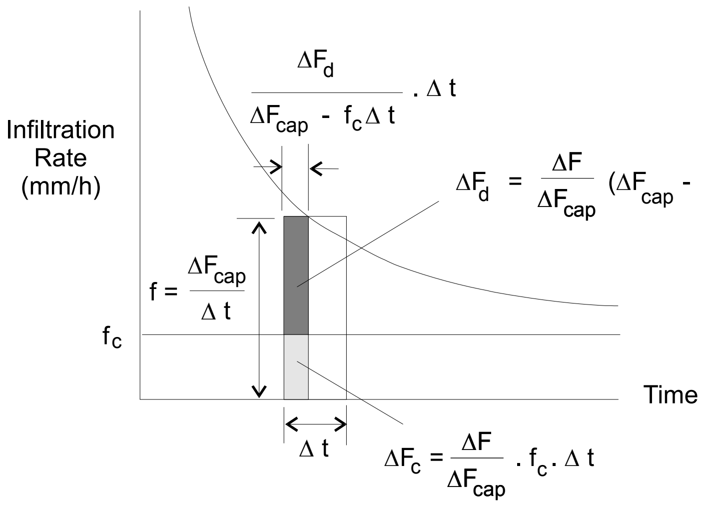


Figure 5.11 Infiltration Capacity Calculation Procedure

(f) Combination of Hydrographs

The time-area method is applied separately to the paved, supplementary and grassed area portions of the catchment. *DRAINS* allows for a supplementary area depression storage and time of travel. (These must both be set to zero if you wish to exactly reproduce ILSAX hydrographs.)

The process for paved and supplementary areas is shown in Figure 5.12. Hyetograph values are scaled (by area/360) to convert intensities to flowrates in m^3/s.

The more complex process for grassed area runoff is shown in Figure 5.13. This diagram is actually an oversimplification. Some details not shown are that:

- the process is actually a step-by-step one, mixing loss and routing calculations for a number of strips across a sub-catchment, and allowing for water running from one strip to another;
- supplementary area runoff is added to the grassed area flows; and
- depression storage is actually calculated after the infiltration is calculated.

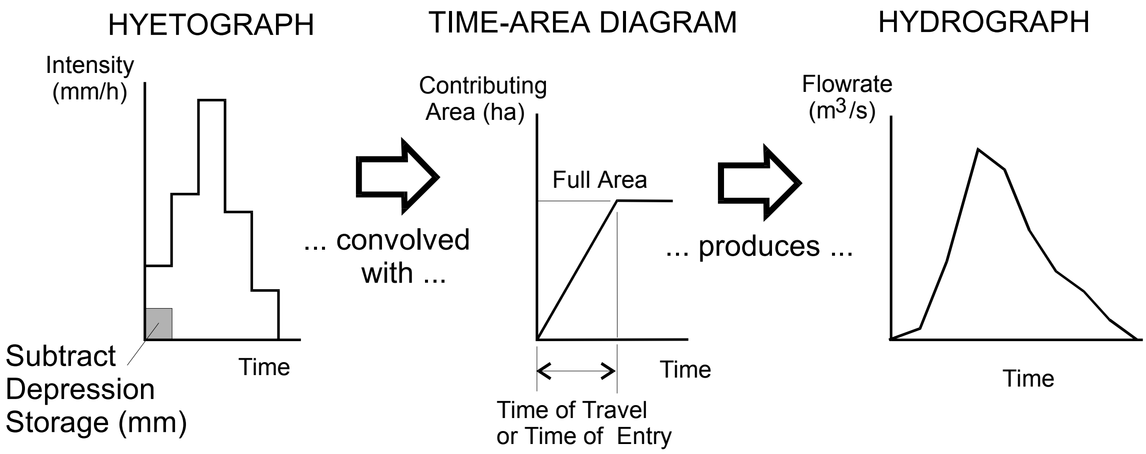


Figure 5.12 Calculation of Hydrographs from Paved and Supplementary Areas

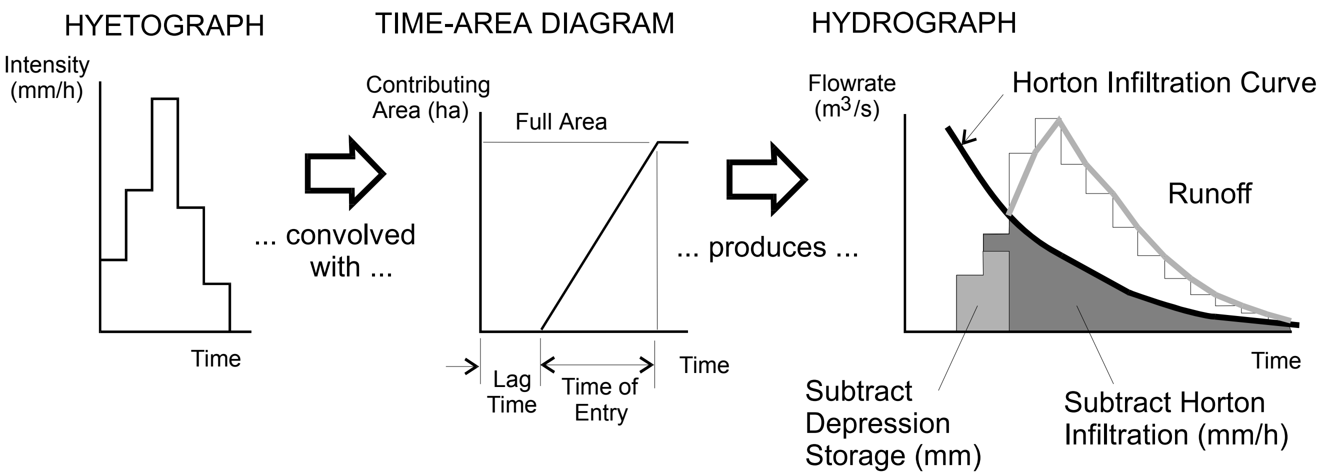


Figure 5.13 Calculation of Hydrographs from Grassed Areas

As explained earlier, grassed area hydrographs can be delayed to allow for any time lag occurring when grassed area flows travels over paved surfaces to the pipe system.

All hydrographs in the program are linked to the same time base and are synchronised, and combination of input hydrographs is a straightforward addition process. As shown in Figure 5.14, the supplementary area hydrograph is incorporated in the grassed area hydrograph. This is added to the paved area hydrograph and possible user-provided hydrographs or baseflow, to obtain the total runoff hydrograph coming off the local sub-catchment. Overflows from upstream pits, if present, are then added to this to obtain the total approach flow to a pit, simple node or detention basin.

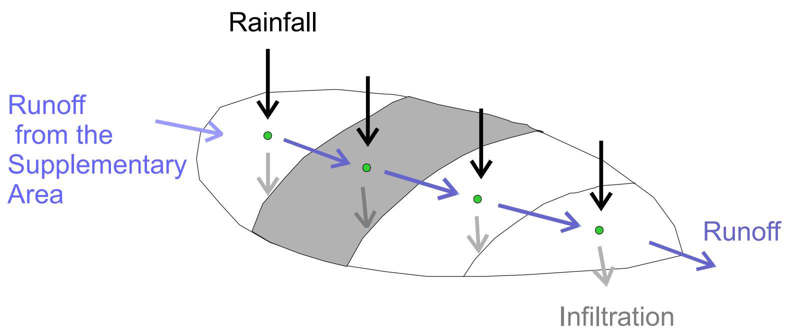


Figure 5.14 Flows between Strips in Time-Area Calculations

At pits, an entry capacity relationship applies, and bypass flows and overflows from the pipe system can occur. With the elaborate hydraulic routing calculations that are applied in *DRAINS*, it is not possible to explain these processes in detail, but generally, various inflow hydrographs are added at each time step, and combined with calculated flows through the upstream pipe system.

5.3.3 Testing and Verification of *DRAINS*

Testing during development has shown that the ILSAX hydrological model has been reproduced exactly in *DRAINS*, with the additional feature of more detailed calculations of supplementary area flows operating satisfactorily. In comparisons with data from gauged urban catchments, ILSAX has been shown to provide results that are at least as good as other urban hydrology programs such as SWMM (see Vale, Attwater and O'Loughlin, 1986; O'Loughlin et al, 1991; and Diamante, 1997, 2000). Table 5.7 and
Table **5.8** show comparative results between recorded data, SWMM, ILLUDAS-SA (a predecessor of ILSAX) and ILSAX, showing that the ILSAX Hydrological Model provides a reasonable reproduction of storm flow characteristics.

Table 5.7 ILLUDAS-SA and Observed Results (Mein and O'Loughlin, 1985)

Catchment Name	Storm Date	Total Rain (mm)	Peak Flowrate (m^3/s)		Volume (m^3)	
			ILLUDAS	Observed	ILLUDAS	Observed
Vine Street	6-11-71	89	1.2	1.1	0.54	0.69
Sunshine	5-2-73	88	2.8	2.3	0.64	0.69

Melbourne	15-5-74	81	1.2	1.7	0.49	0.74
	11-10-75	14	1.6	1.6	0.37	0.51
	31-10-75	28	1.4	1.4	0.53	0.60
	29-12-75	29	2.4	1.6	0.29	0.22
	2-11-76	39	2.5	1.6	0.31	0.26
	13-11-76	18	2.5	1.6	0.26	0.27
	7-4-77	113	2.4	2.2	0.54	0.46
	7-8-78	43	0.9	1.4	0.33	0.60
Powells Creek, Strathfield Sydney	18-2-81	25	6.6	4.1	0.34	0.21
	2-3-81	32	14.8	12.0	0.37	0.27
	21-10-81	53	17.7	12.5	0.76	0.60
	14-12-81	38	6.0	5.3	0.37	0.37
	18-1-82	6	2.3	2.7	0.22	0.32
	24-3-82	45	22.4	16.0	0.68	0.38
Berowra Sydney	9-11-80	31	0.6	0.7	0.18	0.18
	29-12-80	38	1.1	1.2	0.18	0.11
	7-1-81	22	0.5	0.3	0.18	0.19
	24-1-81	14	0.3	0.3	0.17	0.18
	7-11-81	10	1.5	0.7	0.17	0.15
	15-11-81	8	0.9	0.8	0.16	0.21
	21-11-81	47	0.7	0.7	0.21	0.25
	19-12-81	16	1.1	0.8	0.19	0.07
	30-9-82	18	0.2	0.1	0.18	0.02

Table 5.8 SWMM and ILSAX Results for Bunnerong Catchment, Maroubra, Sydney
(Vale, Attwater and O'Loughlin, 1986)

Storm Date	AMC	Total Rain (mm)	Peak Flowrate (m^3/s)			Runoff Volume (m^3)		
			SWMM	ILSAX	Obser-ved	SWMM	ILSAX	Obser-ved-
1-3-77	4	40.5	1.68	1.44	1.02	20.3	17.2	8.78
5-3-77	4	12.3	0.96	1.19	0.55	5.49	4.87	1.98
3-3-78	1	34.8	3.21	2.91	1.64	17.8	14.6	6.59
18-3-78	2	60.2	3.14	3.08	1.56	30.0	25.2	11.9
18/19-3-78	4	14.4	1.39	1.75	0.90	6.58	5.93	3.23
19/20-6-79	2	49.6	2.41	2.20	1.37	23.9	20.7	8.03
20/21-6-79	4	20.5	1.30	1.46	0.57	9.52	8.36	2.61
17-3-83	4	36.0	4.46	4.66	2.11	22.1	27. 0	5.25
5-11-84	2	169.1	4.69	4.58	1.81	94.3	95.0	25.4
6-11-84	4	4.47	0.26	0.40	0.31	1.21	1.50	0.75
6/7-11-84	4	17.0	0.56	0.60	0.36	6.80	6.89	3.06
8/9-11-84	4	89.3	3.33	4.21	1.70	54.6	58.6	14.3

Table 5.9 and Figure 5.15 present more recent comparisons between ILSAX, *DRAINS* and observed data for 25 storms recorded at the University of Technology, Sydney gauging station at Hewitt, Penrith. This and other comparisons with data recorded at Penrith (Pereira, 1998; Tran, 1998) have shown that ILSAX and *DRAINS* produce similar hydrographs at catchment outlets, except in large storms where backwater effects influence the pipe system hydraulics.

Table 5.9 Comparisons between ILSAX and *DRAINS* Calculated Flows and Observed Flows at the Hewitt Gauging Station, Penrith, Sydney
(O'Loughlin, Stack and Wilkinson, 1998; Shek and Lao, 1998; Chan, 1998)

Storm Date	AMC	Peak Flowrate (m^3/s)			Runoff Volume (m^3)		
		ILSAX	*DRAINS*	Obs.	ILSAX	*DRAINS*	Obs.
23-1-92	1	3.28	3.06	3.97	5452	4540	7944
23-2-92	1	0.92	0.94	0.92	2251	2162	1973
21-12-92	2	1.26	1.30	1.26	3368	2920	4257

13-11-93	1	0.42	0.42	0.42	1822	1791	2787
18-11-93	3	0.34	0.38	0.34	1115	1096	1140
1-2-94	1	0.72	0.76	0.65	827	1547	593
12-2-94a	2	0.56	0.52	0.54	1192	1160	1042
12-2-94b	3.6	0.36	0.35	0.37	3034	3018	3158
15-2-94	3	6.49	6.51	3.87	18071	14885	11683
7-3-94	1	0.62	0.63	0.47	1064	1046	858
9-3-94	3.7	0.39	0.40	0.36	2277	2206	2366
29-3-94	3	0.48	0.47	0.39	607	586	405
29-3-94	2	0.46	0.46	0.32	1426	1377	1080
30-3-94a	3.6	1.64	0.99	1.62	1335	1310	1263
30-3-94b	3.7	0.95	1.45	0.95	2705	2280	2003
20-11-94	3	1.90	1.70	2.69	1314	1163	1735
25-12-94	1	0.23	0.24	0.22	3009	2937	2744
1-1-95	1	2.08	1.83	2.55	2663	2118	2486
14-4-95	1	0.24	0.25	0.16	968	923	565
15-4-95	2	0.20	0.20	0.15	809	813	604
2-5-95	1	0.15	0.16	0.12	822	815	654
5-5-95	3	0.27	0.30	0.41	4275	4238	4957
13-5-95	2	2.06	1.95	2.49	4053	3655	5446
16-5-95	4	0.33	0.36	0.88	5460	5504	11358
25-5-95	2	0.63	0.63	0.67	778	824	886

5.3.4 Rational Method Procedures

DRAINS offers three options for the rational method, which can be mixed together in a single system. If your version of *DRAINS* is enabled to run the rational method, it is chosen by selecting a rational method model as a default in the Hydrological Model Specifications dialog box opened from the **Project** menu.

The first option available in the Rational Method Model property sheet that is called from the Hydrological Model Specifications box is a general rational method procedure. It is necessary to specify four runoff coefficients - an impervious and a pervious area coefficient for design, and another set of these for analysis.

For a particular sub-catchment, the rational method is applied as follows:

$$Q = (C_{imp} . A_{imp} + C_{perv} . A_{perv}) . I \qquad \text{… (Equation 5.9)}$$

where Q is the design flowrate in m^3/s,
C_{imp} and C_{perv} are impervious and pervious area runoff coefficients
A_{imp} and A_{perv} are the impervious and pervious areas (ha), and
I is the rainfall intensity (mm/h) corresponding to the appropriate time of concentration.

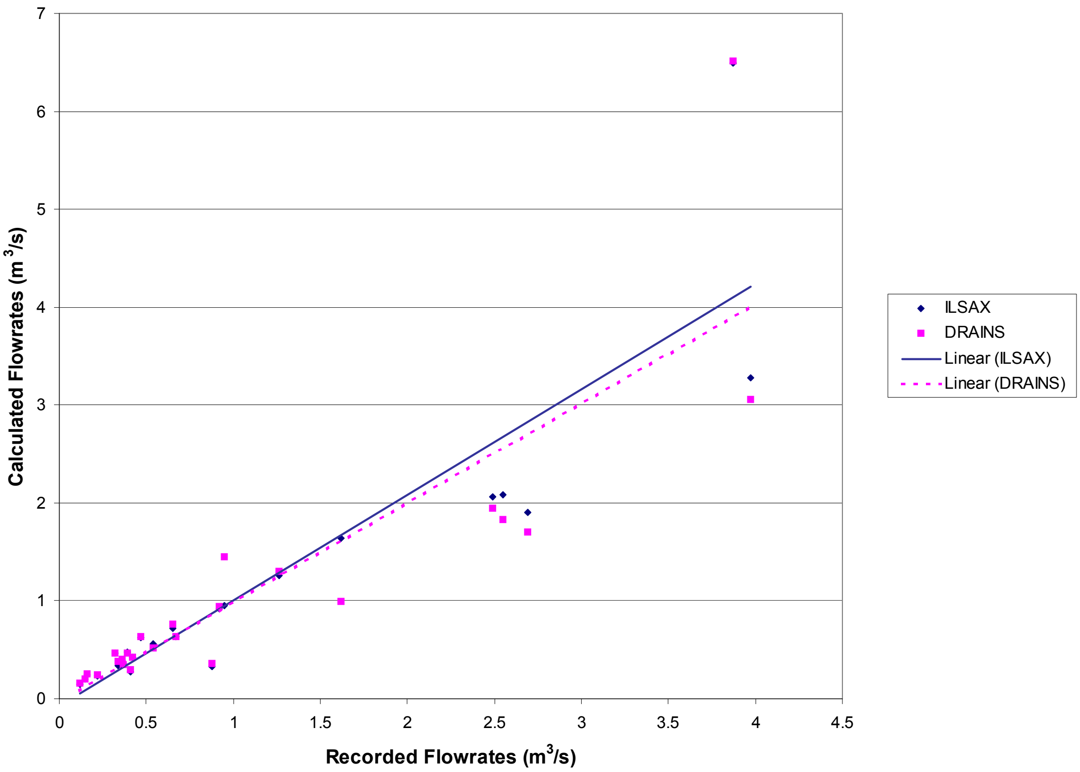


Figure 5.15 Hewitt Results

DRAINS performs a search between 5 minutes and the (usually longer) times specified for the impervious and pervious areas, to find the time that provides the greatest value of Q = C.I.A, overcoming the partial-area problem whereby the lower part of a catchment produce a higher estimate of a flowrate than the total catchment.

Rational method times of concentration are specified in exactly the same way as ILSAX model times of entry in the property sheet for sub-catchments, as described in Section 5.3.2(d).

The first, general method is a 'plain' implementation that has no special fixed features, and can be applied outside Australia, or within Australia if the user wants to depart from the *Australian Rainfall and Runoff*, 1987 method. The second method, from *Australian Rainfall and Runoff* (institution of Engineers, Australia, 1987), is fully explained in that publication. C_{10} values must be entered for impervious and pervious areas. These are 10 year average recurrence interval (ARI) runoff coefficients that are adjusted for other ARIs by multiplying the C_{10} values by the frequency factors shown in Table 5.10. The value for the impervious area is always 0.9.

Table 5.10 Rational Method Frequency Factors

ARI (years)	**Frequency Factor**
1	0.80
2	0.85
5	0.95
10	1.00
20	1.05
50	1.15
100	1.20

The pervious area runoff coefficient is calculated from the formula:

$$C_{10} = 0.1 + 0.0133\ ({}^{10}I_1 - 25) \qquad \text{…(Equation 5.10)}$$

with upper and lower values of 0.1 and 0.7. ${}^{10}I_1$ is the 10 year ARI, 1 hour rainfall intensity, used as an index of the rainfall climate.

The third method is taken from the Australian / New Zealand Standard AS/NZS 3500.3.2. This gives different procedures for Australia and New Zealand, and only the Australian procedure is implemented in *DRAINS* at present. In the Rational Method Model property sheet, this option requires that only the 10 year ARI, 1 hour rainfall intensity ${}^{10}I_1$ be entered. This is used to determine the pervious area C value using the above equation. This runoff coefficient is adjusted upwards by 0.1 for clay soils and downwards by 0.1 for sandy soils. The frequency factors from Table 5.10 are applied with a factor of 1.25 being used for ARIs greater than 100 years. The runoff coefficient for roofs is assumed to be 1.0 and that for impervious surfaces at ground level to be 0.9.

Only a property site itself is considered in these calculations. The rational method formula is expanded to allow for the three surface types:

$$Q = I\ (C_r A_r + C_i A_i + C_p A_p) / 3600 \qquad \text{… (Equation 5.11)}$$

where A_r, A_i and A_p are the areas of roofs, impervious areas and pervious areas in the sub-catchment being considered. In calculations, the time of concentration is fixed, at 5 minutes.

All methods require intensity-frequency-duration (I-F-D) data that is entered in the Rational Method Rainfall Data property sheet opened from the **Rainfall Data…** option in the **Project** menu.

5.3.5 The Extended Rational Method

A number of methods have been developed for extending the rational method to produce hydrographs, usually by assuming a triangular or trapezoidal shape. In the US, a Modified Rational Method (Poertner, 1981) has been applied in many locations. This produces hydrographs corresponding to uniform rainfall blocks of various durations, which can be used to model detention basins in the same way that can be done using *Australian Rainfall and Runoff* design rainfall patterns.

DRAINS presents a variation on this method named the Extended Rational Method (ERM), which is available if the rational method is enabled in the hardware lock used. It was introduced to meet the needs of users who wish to develop hydrographs that are consistent with Rational Method flowrates derived using the methods from *Australian Rainfall and Runoff*, 1987 and the *Queensland Urban Drainage Manual*, 1992. While the ILSAX hydrological model in *DRAINS* should produce superior results to the rational method due to the testing and verification described in Section 5.3.3 and previous parts of this chapter, it cannot provide similar peak flowrates to the rational method across a range of ARIs and storm durations.

The ERM employs the same time-area routing procedure as the ILSAX model rather than assuming hydrograph shapes. The loss model is different, applying a continuing loss to all blocks of rainfall. When the ERM was first released, it assumed a constant continuing loss but inconsistencies were found when it was applied with storms of various durations. The ERM assumes a continuing loss proportional to rainfall intensities.

The ERM requires the same input data as the ARR87 rational method (Figure 1.39) but runs with rainfall patterns or hyetographs, rather than intensities from an I-F-D relationship. When applied with the design storm patterns from *Australian Rainfall and Runoff*, 1987 Chapter 3 the peak flows obtained from a set of

design storms will differ from those given by the ARR87 rational method. The synthetic storm option in the Rainfall Data property sheet (Figure 2.73) has been provided to produce rainfall patterns that incorporate many blocks of rainfall of different average durations that are consistent with the I-F-D duration curves of the design rainfalls. Using these patterns with the ERM, rather than the

The volumetric runoff coefficient (the ratio of volume of runoff to volume of rainfall) obtained from a pervious area with the ERM will be the same as the C_{10} coefficient supplied, adjusted by a frequency factor. The validity of this has been checked using data collected at the Jamison Park Gauging Station in Western Sydney, as shown in Figure 5.16. Results from 80 storms shown in indicate that this is reasonable for this locality. (Peak flow coefficients were derived assuming a time of entry of 20 minutes.)

5.4 Storage Routing Models

Traditionally, storage routing or 'runoff routing' models such as RORB, RAFTS and WBNM have been used for flood studies for larger rural catchments and somewhat smaller semi-urban catchments. These models were introduced in the 1970s as computer models became more widely-used than previously, and methods for modelling urban areas became more important.

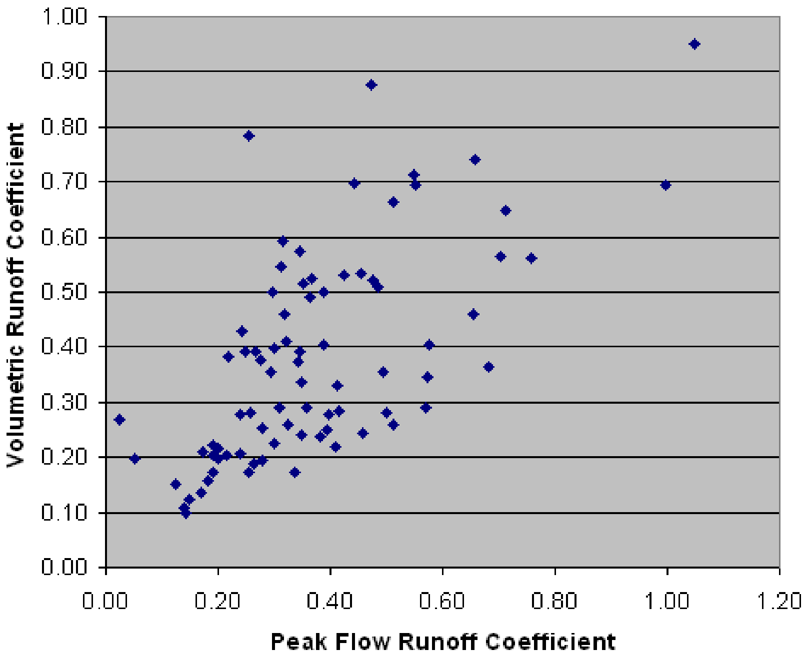


Figure 5.16 Jamison Park Volumetric vs. Peak Flow Runoff Coefficients

Previous models, notably synthetic unit hydrograph procedures, provided a flow estimate at the outlet to a catchment. By dividing the catchment into sub-areas, the storage routing models provided flood estimates at several points throughout the stream system. They also allowed hydrological losses to be varied across the catchment area, reflecting various soil types. Since these models are essentially networks of storages, detention basins and reservoirs can be easily incorporated.

RORB, RAFTS and WBNM belong to a class of models termed runoff routing models, which also includes models based on unit hydrograph and kinematic wave calculations. Runoff routing models can 'route' a hydrograph from one geographical location to another, allowing for changes such as translation and attenuation of the hydrograph, as shown in Figure 5.17.

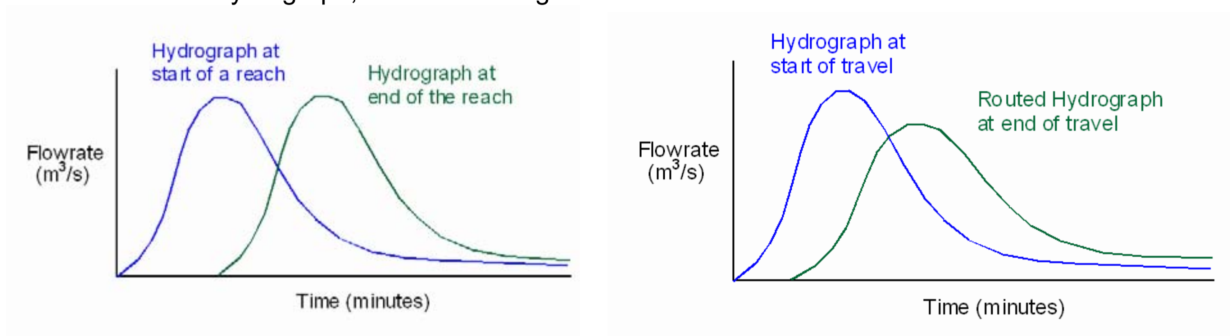


Figure 5.17 Translation and Attenuation Effects on Hydrographs

The basic non-linear model used in Australian storage routing models was developed by Eric Laurenson. RORB, a practical computer application of this model, was produced by Eric Laurenson, Russell Mein and Tom McMahon at Monash University, Melbourne in the mid-1970s. At the same time, the RSWM (Regional Stormwater Model) was developed by Allan Goyen of Willing & Partners and Tony Aitken of SMEC. These models were immediately popular, as they filled a need for modelling mixed rural and urban catchments, allowing for soil and rainfall variability, and providing flow estimates at points throughout the catchment. In 1979, they were followed by the WBNM (Watershed Bounded Network Model) of Michael Boyd , David Pilgrim and Ian Cordery.

Initially, these models were run on mainframe and mini computers. RAFTS (Runoff Analysis and Flow Training Simulation), an enhanced version of RSWM, was released in 1983 and sold commercially by Willing & Partners (later WP Software and XP-Software). This includes continuous modelling processes as well as the storage routing model discussed here. A version for PCs was released in 1987. A PC version of RORB was released in 1988.

WBNM was revised in 1987 and a new version was produced by Michael Boyd, Ted and Rudy VanDrie in 1994, which modelled urban catchments. WBNM2000, introduced in 1999, used a different structure to earlier models and added many features.
Storage routing calculations are carried out over a series of time steps, with the information obtained from solving equations at one time step being used as an input to the next step. Each of the models available in *DRAINS* has been developed on different principles. RORB performs calculations based on the equation:

$$S = k_c . k_r . Q^m = k_c . (l_i / l_c) . Q^m \qquad \text{… (Equation 5.12)}$$

where S is storage (m^3),
k_c and m are parameters, with m being in the range 0.65 to 0.85,
k_r is a routing factor for a particular sub-catchment, being the ratio of the stream length running through that sub-catchment, l_i, and the average flow distance from sub-catchments to the catchment outlet, l_c, calculated by dividing the sum of catchment areas multiplied by their distances from the outlet by the total catchment area, $\Sigma(A_r.d_r) / A$, and
Q is flowrate (m^3/s).

k_c acts as a calibration parameter, enabling the model's results to be varied and fitted to recorded hydrographs. A k_c of 0.0 will perform no routing, so that values of rainfall excess and flows from upstream storages will pass through a sub-catchment unchanged. A k_c that is very large will delay flows considerably, so that flowrates will be very low. By adjusting k_c, the peak of a calculated hydrograph can be varied over the range from the peak rate of rainfall excess to zero. Decreasing k_c increases flowrates.

Allowance is made for different channel conditions by multiplying the routing factors by the values in Table 5.11, in which S_c is the reach slope (%).

Table 5.11 Reach Adjustment Factors in RORB Model

Reach Type	Multiplier
Natural	1.0
Excavated and unlined	$1/(3S_c^{0.25})$
Lined or piped	$1/(9S_c^{0.5})$
Drowned (by a reservoir)	0.0

The routing through a sub-catchment in a RORB model will depend on the length of the stream channel through the sub-catchment and the average distance to the outlet, l_c. When combining a RORB model with an ILSAX model, the lengths of channels and pipes in the ILSAX model will be used to calculate lc. If a k_c value from a stand-alone RORB model is used in this case, it will result in an incorrect routing calculation. It will be necessary to use a different k_c that can be derived or by dividing the k_c derived for a stand-alone model by l_c for the new model multiplied by l_c for the original RORB model. Since *DRAINS* does not reveal the lengths to outlets, it will be easiest to determine a new k_c by trial and error, matching the peak flowrates defined by the original model.

For sub-catchment routing, RAFTS uses the equation:

$$S = BX . IBFL . PERN . 0.285 A^{0.52}. (1+U)^{-1.97}. S_c^{-0.50}. Q^{0.715} \qquad \text{… (Equation 5.13)}$$

where BX is a calibration factor similar to RORB's k_c,
IBFL is a factor for modelling overbank flow,
PERN is a factor that adjusts the catchment routing factor to allow for catchment roughness,
A is the sub-catchment area (km^2),
U is the fraction of the catchment that is urbanized, and
S_c is the main drainage slope of the sub-catchment.

For routing along stream reaches, RAFTS applies a translation over a nominated time, or performs Muskingum-Cunge routing based on the stream cross-section and roughness.

For sub-catchments, WBNM uses the routing equation:

$$S = 60 \,.\, LP.\, A^{0.57}.\, Q^{0.77} \qquad \text{… (Equation 5.14)}$$

where LP is a lag parameter and A is catchment area (ha).

Values of the WBNM lag parameter are typically between 1.3 and 1.8. This can be used to calibrate the model in a similar way to the RORB parameter, k_c. WBNM2003 also allows for translation and Muskingum routing in stream reaches.

For stream reaches, a similar equation is used:

$$S = 0.6.\, 60 \,.LP.A^{0.57}.Q^{0.77} \qquad \text{… (Equation 5.15)}$$

with the 0.6 allowing for the routing effects in the reach, the length of which is related to the area of the catchment through which it runs, A. A stream lag factor can be applied to allow for different types of channel. Indicative values are shown in Table 5.12.

Table 5.12 Stream Lag Factors used in WBNM

Reach Type	Stream Lag Factor
Natural channel	1.0
Gravel bed with rip-rap	0.67
Excavated earth	0.5
Concrete lined	0.33
Drowned (by a reservoir)	0.0
No lag, artificial link	0.0

Modelling facilities based on RORB, RAFTS and WBNM have been included in *DRAINS*. The three models have different structures, as shown in Figure 6.18: RORB has a well-defined structure, with nodes located close to sub-catchment centroids. Routing is only carried out in the stream reaches. There is modelling of losses at nodes but no routing.

By contrast, RAFTS can carry out routing at nodes representing sub-catchments, and also in stream reaches, where flows can be translated or routed using the Muskingum-Cunge method, based on the reach cross-section and roughness. The routing within sub-catchments differs from RORB and WBNM in that flows are commonly routed through 10 successive non-linear storages, as indicated in one of the sub-catchments in Figure 5.18.

In WBNM, routing occurs at the sub-catchment nodes and in stream reaches that convey runoff from upstream sub-catchments through the local sub-catchment. Like RAFTS, it is flexible, and can be set out in different configurations.

To fit these different structures into the *DRAINS* framework, it has been necessary to apply different property sheets and relationships between model sub-catchments and stream routing reaches. These are described in Chapter 2. For stream channels, routing can also be undertaken by methods such as the Muskingum Method, lag and route methods, Muskingum-Cunge routing and hydraulic routing using methods such as kinematic wave calculations. *DRAINS* employs the latter in RAFTS-style stream routing reaches, following a method given in Chapter 9 of *Open Channel Hydraulics* by F.M. Henderson (1966).

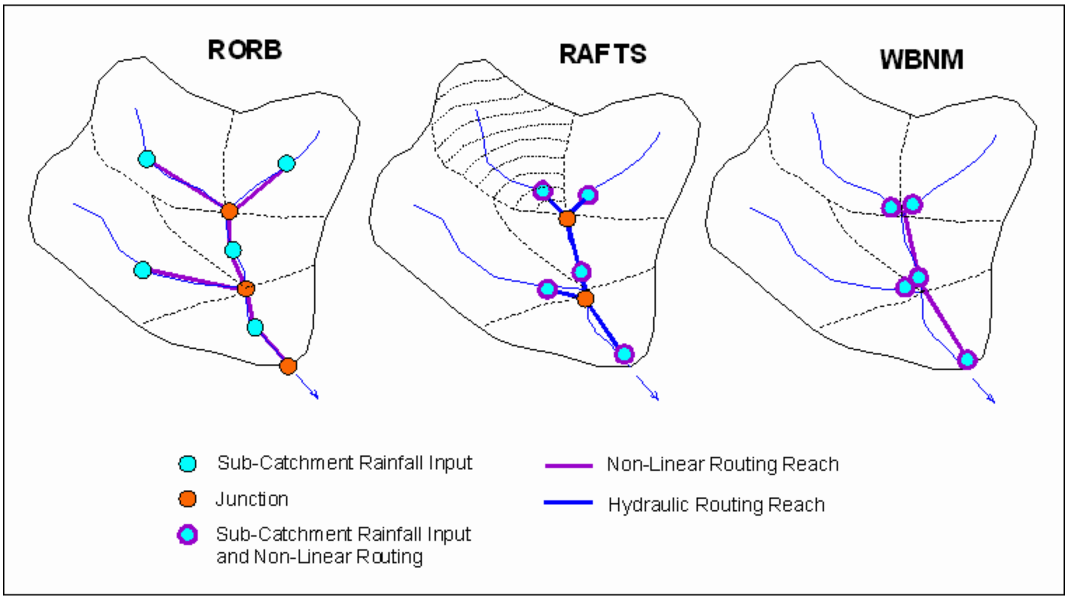


Figure 5.18 Structure of Three Storage Routing Models

5.5 Pit Inlet Capacities

5.5.1 General

The inlet capacity of pits is a vital factor in the modelling of piped stormwater drainage systems in major storm events, separating surface overflows from underground pipe flows. Pits can be distinguished by their *form*, as grated pits, kerb inlets, or as combinations of these. The latter two types are preferred in Australia. Pits can also be distinguished by the situation in which they are applied. On-grade pits, shown in Figure 5.19, are located on slopes in a channel such as a street gutter, with water flowing to them, and with any bypass flows escaping. Sag pits are located in hollows or depression, where the incoming flows for a pond over the pit. These situations are hydraulically different and different forms of relationships are used to describe their inlet capacities.

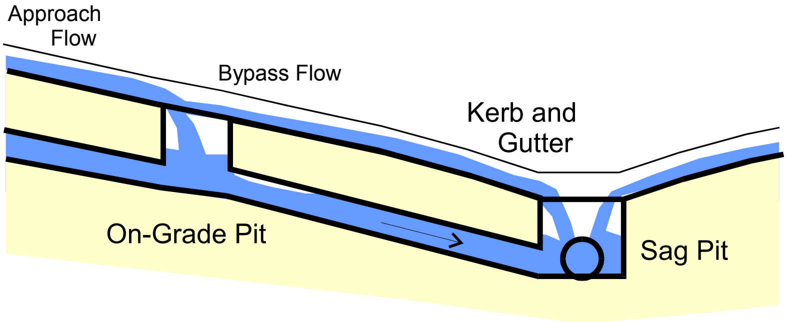


Figure 5.19 On-Grade and Sag Pits

On-grade pit inlet capacities are defined as a relationship between the inlet flow or capture and the approaching flow. This flow is affected by the road cross-section properties and its longitudinal slope, as well as the characteristics of the inlet. Different road and gutter cross-sections and roughnesses will create different widths and velocities of flow approaching the pit. Since there is no direct theoretical relationship covering all of these factors, empirical relationships have been established from laboratory tests and field observations.
Figure 5.20 shows the relationships for kerb inlets on grade measured in hydraulic model studies published by the N.S.W. Department of Main Roads (1979). As the magnitude of the approach flow increases, the percentage of the flow captured will decrease. This is represented by the curved line becoming gradually flatter and crossing the dotted lines that indicate various percentages of capture.

Sag pits can be modelled more easily, as the theory of weir and orifice flow can be applied to relate inlet capacities to depths of ponding. Experimental investigations have confirmed the following weir equation given in *Australian Rainfall and Runoff* (Institution of Engineers, Australia, 1987, page 303).

$Q_i = 1.66 . P . d^{1.5}$ up to about 0.12 m of ponding … (Equation 5.16)

where Q_i is inlet flowrate (m^3/s),
P is the perimeter length of a grated pit, excluding the section against the kerb, and
d is the average depth of ponding (m).

Orifice flow can occur above 0.12 m for a grate and 1.4 times the slot height for a kerb inlet, though there is a large transition zone for grates, in which either flow mechanism may occur. Most cases of interest to designers, including major flows, are described by the weir equation.

At low flows all of the approach flow will be captured, but at a certain flow, some bypass will start to occur.

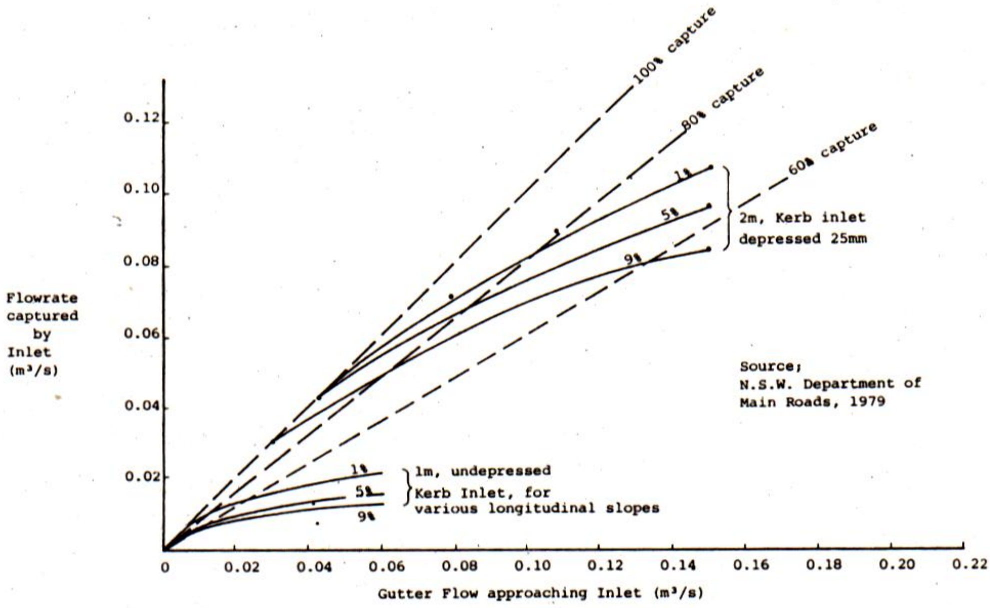


Figure 5.20 Entry Capacities for Kerb Inlets on Grade

There have been many sets of hydraulic tests undertaken to define inlet capacities. Tests have been conducted in Australia by the NSW Public Works Department for the NSW Department of Main Roads (now NSW Roads and Maritime Services) and NSW Department of Housing, by the University of South Australia for various Queensland, Australian Capital Territory and South Australian bodies, and by the Victorian Country Roads Board (VicRoads). These have produced a rather confusing array of results, from which it is difficult to generalise.

In addition, the published relationships do not cover the range of high flows expected to occur in severe storm events such as 100 year average recurrence interval and probable maximum precipitation events. Almost all studies were intended to develop relationships for routine design, and did not deal with very high flows. Extrapolation of these relationships is an uncertain process.

The main factors influencing inlet capacity of on-grade pits are the length of the pit, the depression or crossfall of the gutter at the pit, and the longitudinal slope. Generally the greater the longitudinal slope, the lower the capture rate. Pit size and grate type are the main factors affecting sag pit capacities. The US Federal Highway Administration Hydraulic Engineering Circular No. 22, *Urban Drainage Design* (2009) includes a set of semi-theoretical procedures for defining inlet capacity relationships. Pezzaniti, O'Loughlin and Argue (2005) have used these as a basis for extrapolating existing relationships, and for developing relationships where none are available.

5.5.2 Pit Inlet Capacities in *DRAINS*

At every time step in *DRAINS* calculations, the program applies pit inlet capacity relationships to the surface flow arriving at each inlet. If the flowrate arriving at an on-grade pit causes the storage to exceed its specified volume, the surplus flow becomes a bypass. If overflows occur due to limitations on pipe reach capacity, these are added to the bypass flows.

Two types of entry conditions can be modelled in *DRAINS*:

- sag pit, at a low point where water will pond, up to some limit, with any overflows being directed downstream or out of the system, when the ponded water level rises to the spill level.

- on-grade inlet, on a sloping gutter, from which any flows bypassing the inlet can run away, with bypasses or overflows being directed to downstream pits or out of the system.

At one stage there was also an ILLUDAS pit type that no longer appears in *DRAINS*. It is described in the Help System.

Initially, *DRAINS* followed ILSAX (O'Loughlin, 1993) by using equations employing various curve-fitting factors, but this approach was superseded by inlet capacity relationships defined as a series of points, as shown in Section 2.4.6, rather than by equations. Further information is given in the DRAINS Help system. Sets of inlet capacity relationships are available to users of *DRAINS* in the new format. These were obtained from published sources, mostly smoothed graphs fitted to experimental data from the testing rigs operated by the University of South Australia (www.unisa.edu.au/uwrc/rig.htm) and the New South Wales Government Manly Hydraulics Laboratory (http://mhl.nsw.gov.au/www/welcome.html).

The new relationships have been extrapolated well beyond the ranges of the published relationships using hydraulic principles, allowing for approach flows up to 2.5 m^3/s for on-grade pits and depths of ponding of up to 0.6 m for sag pits. None of these relationships have been approved by the originating authorities. It is up to each user of *DRAINS* to determine whether they are suitable for their purposes. Users can readily modify the relationships.

The available relationships for New South Wales apply to the pits described in Table 5.13.

Table 5.13 New South Wales Pits

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
NSW Roads and Maritime Services, (formerly called the RTA and DMR) pits (DMR, 1979; O'Loughlin, Darlington and House, 1992) and tests carried out for the RTA in the 1990s	SA1	1.0 m wide x 0.15 m high	1 m x 0.45 m	A kerb inlet-grate combination depressed by 25 mm below normal gutter levels
	SA2	1.83 m wide x 0.15 m high	0.915 m x 0.45 m	As above
	SA5	2.745 m wide x 0.15 m high	0.915 m x 0.45 m	As above
	SF1	Median pit with cover	none	As above
	SO V-Channel	None	0.7 x 0.7 m or 0.7 x 1.4 m	V shaped pits located in V-Channels
	SK V-Channel	None	0.825 x 0.7 m or 0.825 x 1.4 m	V shaped pits located in V-Channels
Hornsby Council Pits	0.9, 1.2, 1.8, 2.4, 3.0, 3.6 and 4.2 m wide lintel	0.9, 1.2, 1.8, 2.4, 3.0, 3.6 or 4.2 m wide x 0.15 m high	0.915 m x 0.45 m	Essentially the same type as the RTA Pits
NSW Dept. of Housing (1987) RM10 Pit	1.68, 1.8, 2.4 or 3.0 m lintel	1.68, 1.8, 2.4 or 3.0 m wide by 0.15 m high	0.9 m x 0.5 m	A similar type of pit to the RTA pits
NSW Dept. of Housing (1987) RM7 Pit		none	0.9 m x 0.5 m	A grated pit used on accessways
Sutherland Shire Council (1992)	0.85, 1.2, 1.8, 2.4 and 3.0 m lintel	0.85, 1.2, 1.8, 2.4 and 3.0 m wide by 0.15 m high	0.9 m x 0.5 m	No grate or Durham Cast iron grate

The set of pits shown in Figure 5.21 was the basis of both the RMS (RTA) and Hornsby Council relationships, which have different forms. The former allows for longitudinal slopes while the latter provides a single relationship for all slopes.

Relationships developed for Australian Capital Territory are detailed in Table 5.14

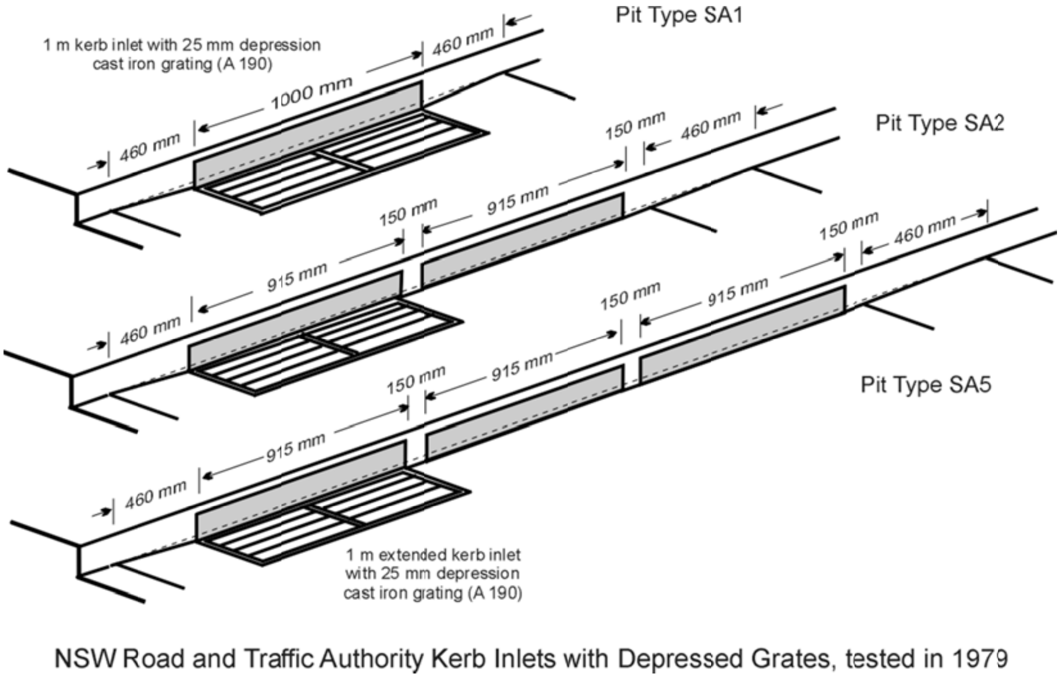


Figure 5.21 Type SA1, SA2 and SA5 Pits tested for the NSW Department of Main Roads

Table 5.14 ACT Pits

(Source: ACT Government *Urban Stormwater, Standard Engineering Practices*, Edition 1, www.act.gov.au/storm/)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Sump	QS	0.6 m long	none	Only for sags, in three types of gutters
Sump	R	1.3 m long	none	In three types of gutters: KG, MLBK & MKG
Sump	Double R	2.6 m long	none	As above
Sump	Triple R	3.9 m long	none	As above

Victorian relationships obtained by extrapolating the curves given in the VicRoads *Road Design Guidelines Part 7, Drainage*, 1995 are available for the pits shown in Table 5.15.

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Table 5.15 Victorian VicRoads Pits

(Source: VicRoads Manual)

Pit Type	**Size**	**Kerb Inlet Dimensions**	**Grate Size**	**Comments**
VicRoads	1.0 and 1.5 m side entry pits	1.0 and 1.5 m wide by 0.10 m deep	none	
VicRoads	1 m grated inlet pit	none	Transverse grates A & B - 1.0 m wide x 0.75, 1.0, 1.5, 2.0 or 2.5 m long	
VicRoads	Grated side entry pit	1.0 m wide x 0.1 m deep	assumed 1.0 m x 0.45 m	

Queensland relationships are outlined in Table 5.16. Queensland has the most comprehensive data of any Australian state. There has been an extensive revision of the original Queensland 2003 relationships, because of the introduction of new pit types and relationships, and new extrapolation procedures.

Table 5.16 Queensland Pits

(2008 Version, Various sources, see Column 1)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Brisbane City Council Pits (from BCC Standard Drawings)	S, M and L, nominally 2400, 3600 and 4800 mm lintel lengths	lintels - 2.04, 3.24 and 4.44 m long x 0.12 or 0.14 m deep	0.90 m x 0.61 m	Separate lip in line (recessed) relationships for D (mountable) and E (barrier) kerbs and two sets of kerb in line relationships for both D & E kerbs. The new relationships supersede the older ones that appear in the DMR *Road Drainage design Manual* (2002) and other manuals. Relationships are given for 2.5 and 3.3% crossfalls and grades from 0.25% to 16% plus sags.
Gold Coast City Council Pits (from GCCC Manuals)	As above	As above	0.90 m x 0.50 m	Separate lip in line relationships for (a) barrier or roll-top kerbs and (b) transverse or longitudinal grates, (c) 2.5% or 3% crossfalls and (d) grades from 0.25% to 16% and sags.
Max Q Drainway Plus (from Max Q catalogue, 2003)	0TP/X, 1TP/X, 2TP/X and 3TP/X	1.0, 2.3, 3.6 and 4.0 m wide x 0.1 m deep lintels	0.66 m x 0.614 m Maxflow and Mannflow Grates or Draincover	With (a) mountable kerb, barrier kerbs with 300 mm and 450 mm channels, (b) 2.5% or 3% crossfalls, (c) 0.25 to 16% grades and sags.
Max Q Stormway (from Max Q catalogue, 2003)	S1000/A, S1600/A, S2400/A, S3600/A and S4800/A	1.0, 2.3, 3.6 and 4.0 m wide x 0.1 m deep lintels	0.85 x 0.51m Macadam, Manning, Grates or Stormcover	With (a) mountable kerb, rollover kerb, barrier kerbs with 300 mm and 450 mm channels, (b) 2.5% or 3% crossfalls, (c) 0.25 to 16% grades and sags.
Max Q Stormway (catalogue)	S1000/H	1.0 m lintel	0.675 x 0.31 m Hazen Grate	For mountable kerbs, 2.5 and 3% crossfalls and grades from 1% to 16% and sags
Humes Drainway Pits (obsolete)	0TC, 1TC, 2TC and 3TC	1.35, 2.7, 4015 and 5.4 m wide x 0.14 m deep	One or two 0.5 m x 0.5 m Hydraflow grate or infill cover	A modular system built around one or two pits with grates
BroPit (obsolete)	1C0T, 1C1T, 1C2T	0.75 m, 2.1 m and 3.45 m wide x 0.10 m deep	none	A modular system made up of pits (C) and troughs (T)
DMR Field Inlet	Single and double	-	0.6 x 0.9 m or 0.6 x 1.8 m	Nominally for sags only, but an on-grade relation assuming 1% grade is included

South Australian relationships are provided in

Table **5.17**. Relationships for Western Australian and Tasmanian Pits derived using US Federal Highway Administration HEC-22 procedures are shown in
Table **5.18** and Table 5.19.

For both on-grade and sag pits, a choke factor can be applied to simulate blockage of the pit. This is 0.0 for no blockage and 1.0 for complete blockage. There is considerable uncertainty about appropriate factors. *Australian Rainfall and Runoff* 1987 indicated typical values of 0.2 for an on-grade pit and 0.5 for a sag. Some Queensland practice applies values of 0.1 for both. It could be argued that a factor of 0.0 should be applied to on-grade pits, which are much less likely to block than sag pits. These are multiplied by the capacity defined by the inlet capacity relationships, whatever magnitude this may be. While this is acceptable for the type of blockage that might occur for sag pits, it may not be realistic for on-grade pits. If you have doubts about this, it would be better to define the required inlet capacity relationship in the pit data base, and to employ this with a blocking factor of zero.

Table 5.17 South Australian Pits

(Source: html files developed by the Urban Water Research Centre of the University of South Australia)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Transport SA	Single Bay	0.9 m long	none	On-grade relationships with and without deflectors
	Double Bay	1.9 m long	none	On-grade and sag relationships with and without deflectors
City of Adelaide	Single Pit	0.9 m long	0.5 m long x 0.54 m wide	On-grade and sag
	Double Pit	1.9 m long	As above	Sag only
City of Campbelltown	Double Pit	1.9 m long	none	On-grade and sag, with and without deflectors
City of Charles Sturt	Single Pit	0.9 m long	none	On-grade and sag, with and without deflectors and transitions
	Double Pit	1.9 m long	none	As above
City of Marion	Double Pit	1.9 m long	none	On-grade and sag, with and without deflectors
City of Mitcham	Single Bay	0.9 m long	0.9m x 0.45m	On-grade without deflectors
	Double Bay	1.9 m long	none	On-grade and sag, with and without deflectors
City of Onkaparinga	Double Pit	1.9 m long	none	As above
City of Playford	Double Pit	1.9 m long	none	As above
City of Port Adelaide/ Enfield	Double Pit	1.9 m long	none	On-grade, with and without deflectors
	Triple Pit	1.9 m long	none	Different bay arrangement, On-grade, with and without deflectors
City of Salisbury	Double Pit	1.9 m long	none	On-grade and sag,' with and without deflectors
City of Tea Tree Gully	Double Pit	1.9 m long	none	On-grade and sag, without deflectors
City of West Torrens	Double Pit	1.9 m long	none	On-grade and sag, with and without deflectors

Table 5.18 Western Australian Pits

(Developed from Department of Main Roads drawings and Generic Spreadsheet using HEC-22 procedures. None are based on measured data.)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
Main Roads Side Entry Gully, Type TEN to DEN	Single Gully	0.88 m long	none	On-grade relationships with allowance for deflectors
Main Roads Gully, TGT to DGT	Single Pit	none	0.92 m long x 0.425 m wide	On-grade and sag
Main Roads Normal Catchpit	Single Grate	none	As above	On-grade and sag, assumed to be used in swales
Main Roads High Flow Catchpit	Single Grate	none	As above, 150 mm above surface	As above

Table 5.19 Tasmanian Pits

(Developed from government drawings and Generic Spreadsheet using HEC-22 procedures. No measured data.)

Pit Type	Size	Kerb Inlet Dimensions	Grate Size	Comments
IPWEA	Single grated Grated deflector Double grated	0.9 m wide 1.865 m wide 1.9 m wide	0.9 x 0.45 m 0.9 x 0.45 m + deflector 1.9 x 0.45 m	At some slopes the double grate pit has the highest capacity; at other grades it is the grated deflector pit
City of Devonport	Double grated extended kerb inlet	1.68 m wide	0.89 x 0.40 m	
Dept. of Infrastructure, Energy & Resources	Mountable kerb	1.0 m wide 1.8 m wide 0.9 m wide	None 0.9 x 0.35 m + deflector 0.9 x 0.35	
	Barrier kerb	As above	As above	
	V-Channel	none	0.98 m x 0.64 m	

5.5.3 US Federal Highway Administration (HEC22) Procedures

The *Hydraulic Engineering Circular No. 22* of the US Federal Highway Administration (2009) (available from www.fhwa.dot.gov/bridge/hyd.htm) contains the only general methodology available for defining inlet capacities for all kinds of rectangular pit. It is applied as a series of equations and procedures, with a semi-theoretical basis. These procedures have been included in a comprehensive 'generic' pit capacity spreadsheet available to *DRAINS* users and the on-grade pit procedures have been incorporated into *DRAINS* via wizards located in the Pit Data base opened from the **Project** menu.

For the gutter and pit shown in Figure 5.22, the on-grade procedure shown in Figure 5.23 applies.

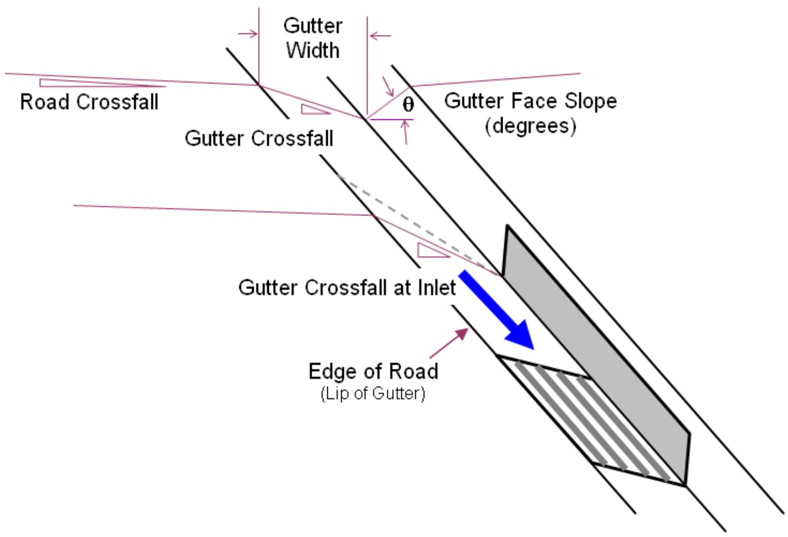


Figure 5.22 Road and Pit Characteristics

Flow is assumed to approach a pit along a gutter. At the pit, the gutter crossfall may become steeper to provide a depression. The pit may be a kerb inlet, a grate, or a combination inlet with both. The latter kerb inlet is assumed to project beyond the grate so that the approaching flow encounters this first. The method requires information on the road cross-section as well as on the inlet characteristics. The grate types detailed in the HEC22 manual are shown in Figure 5.24.

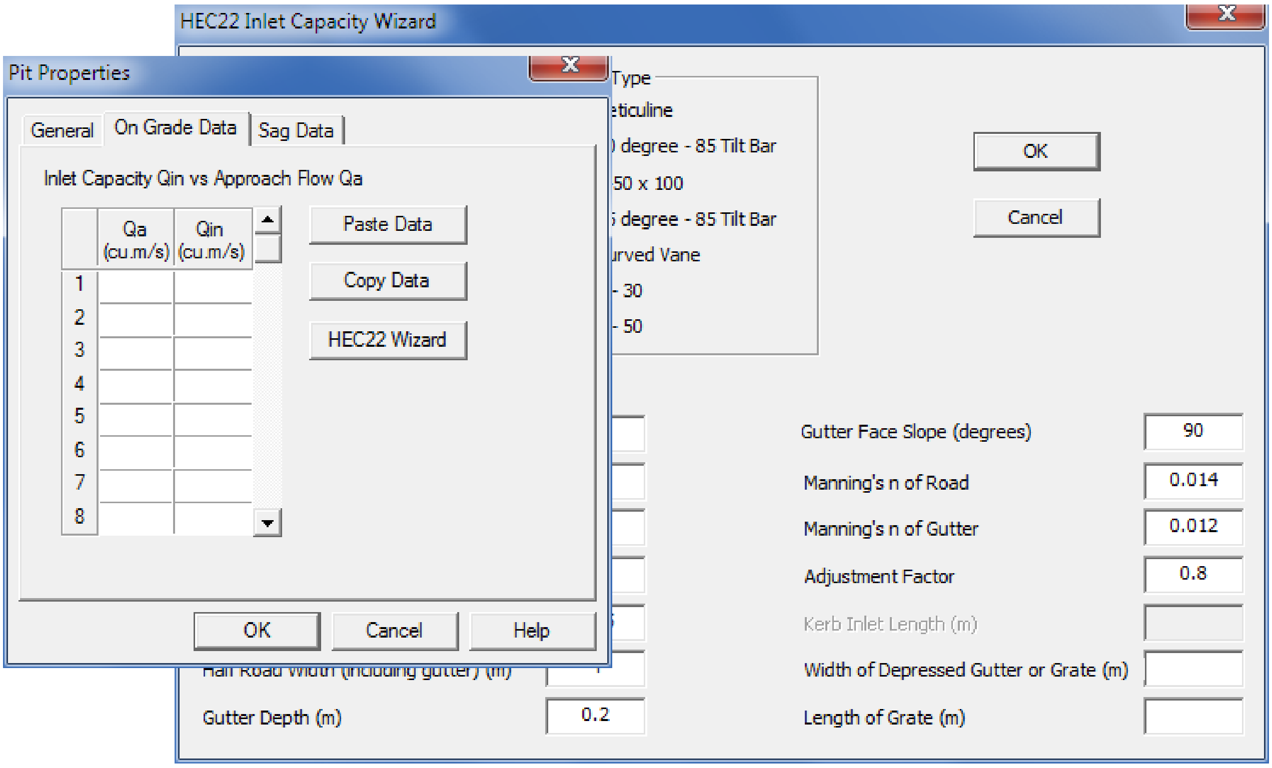
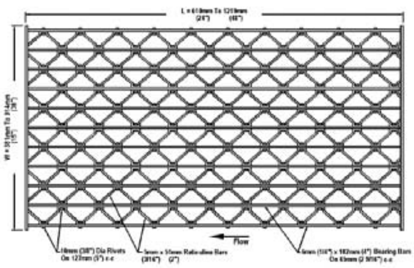
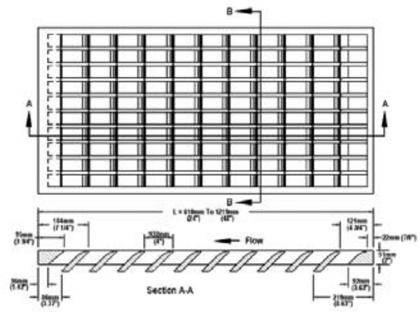


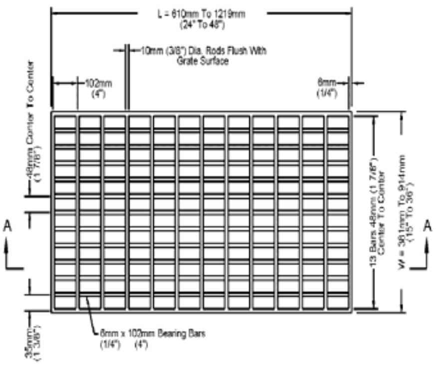
Figure 5.23 HEC22 On-Grade Input Procedure



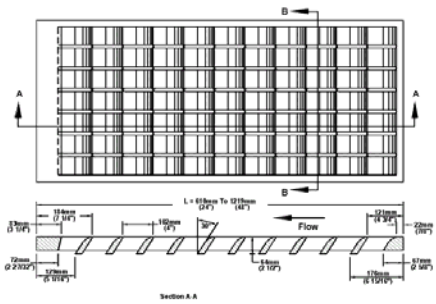
Reticuline



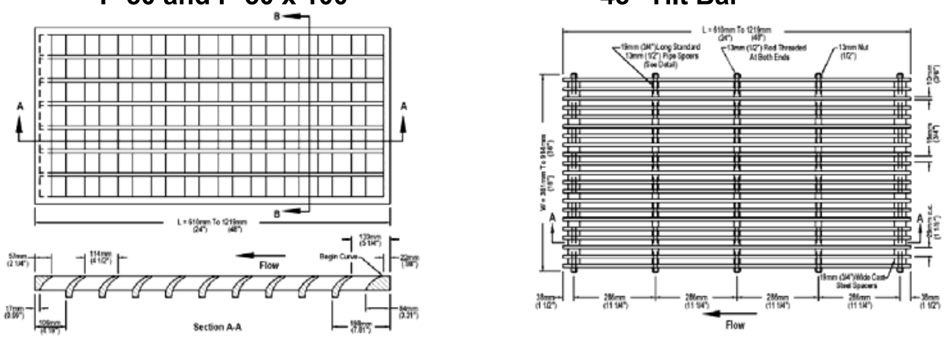
30° Tilt Bar



P-50 and P-50 x 100



45° Tilt Bar



Reticuline P-30

Figure 5.24 HEC22 Pit Types

Once the required data is entered, the required relationship will appear in the Pit Data Base property sheet. This can be checked by copying this and displaying it in a spreadsheet. This procedure can be applied to pits in swales, as well as in street gutters or channels. The dialog box is shown in Figure 5.25, covering the situation shown in Figure 5.26.

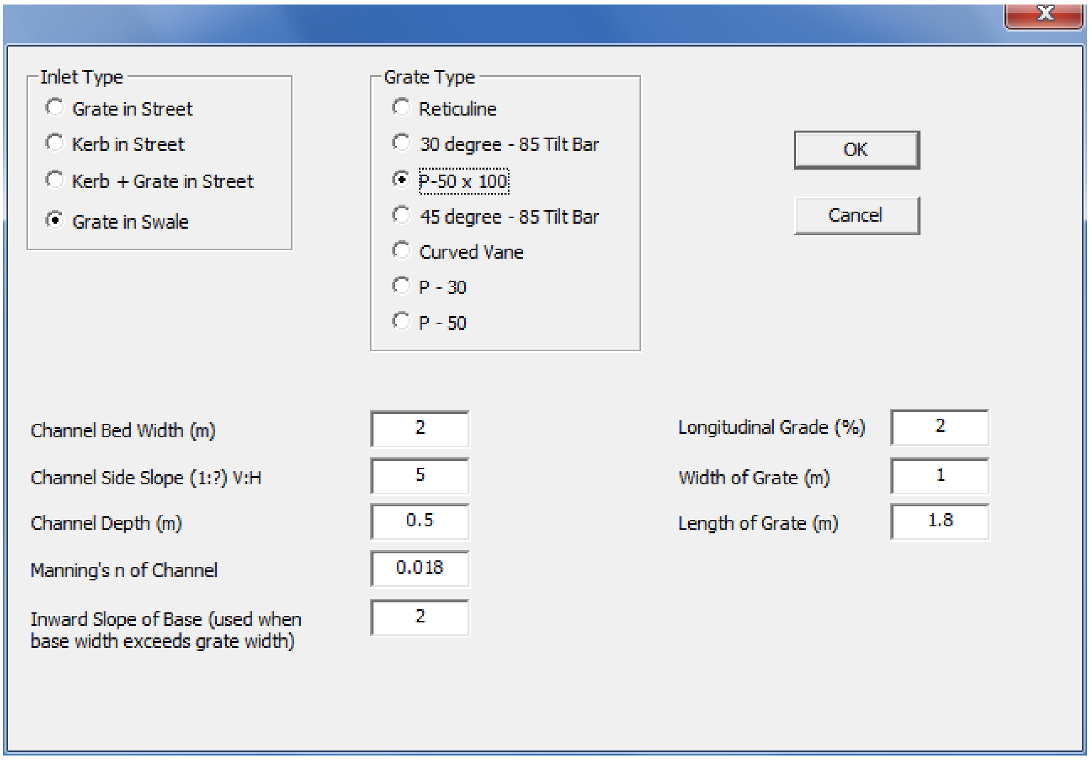


Figure 5.25 Dialog Box for a Pit in a Swale

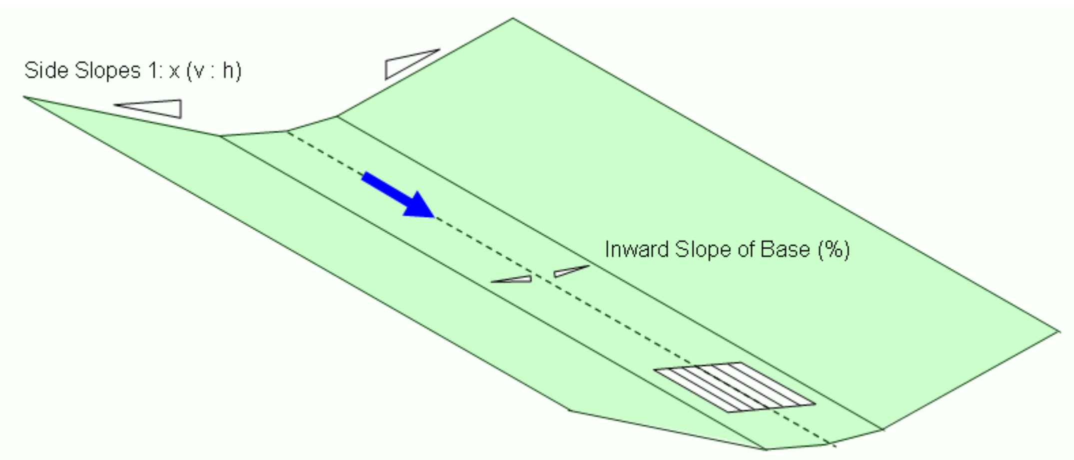


Figure 5.26 Pit in Swale

A similar procedure applies for sag pits. The *DRAINS* wizard shown in Figure 5.27 only operates for grated inlets. This requires information on grate dimensions. (For kerb inlets or combination (kerb inlet + grate) inlets, you can use the 'generic' spreadsheet supplied to *DRAINS* users to develop relationships that can be pasted into the *DRAINS* pit data base.)

The calculations associated with these methods produce results that match laboratory results on pit capacities well in some cases, but rather poorly in others. This issue has been studied by Pezzaniti, O'Loughlin and Argue (2005), who produced the assessments of the accuracy of the HEC22 procedures for on-grade pits shown in Table 5.20. This can be used as a guide to adjusting relationships produced by the HEC22 procedure. Adjustments can be made by copying the relationship produced to a spreadsheet, modifying this as required, and then pasting it back into the Pit Data Base table. Using these procedures, it is possible to derive inlet capacity relationships for all types of pits, including unusual or modified ones.

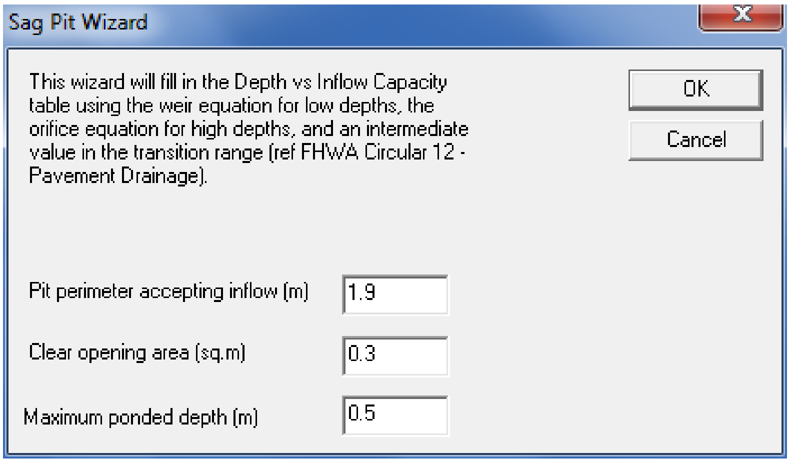


Figure 5.27 Dialog Box for Sag Pit

5.6 Pipe System Hydraulics

5.6.1 General

The hydraulic models used in design and analysis of urban stormwater drainage systems can be considered to operate at three levels:

- open channel hydraulics assuming steady flow and normal depth conditions, described as 'pipe full but not under pressure' in Australia,
- part- or full-pipe flow calculations determining hydraulic grade lines (HGLs) and water surface profiles,
- full hydrodynamic modelling, usually involving a finite difference solution of the partial differential equations for conservation of mass and momentum, the St. Venant Equations.

ILSAX calculations operate at the first level, so their hydraulics is quite limited. The same applies to the calculation of flow characteristics in overflow routes in the standard and obsolete basic hydraulic models.

Table 5.20 Qualitative Indication of the Accuracy of the HEC22 Procedures
(Inlet Capacities from HEC22 Procedure relative to Laboratory Results)

Inlet Type	Approach Flow Range	Approximate Length of On-Grade Inlet		
		1 m or Shorter	Between 1 & 3 m	3 m and Longer
Grate Only	< 0.15 m^3/s	OK	OK	-
Grate Only	0.15 to 0.5 m^3/s	OK	-	
Grate Only	> 0.5 m^3/s	Underestimates by about 25%	-	-
Kerb Inlet Only	< 0.15 m^3/s	25% over for un-depressed inlet, 50% under for depressed	25% underestimate	20% underestimate
Kerb Inlet Only	0.15 to 0.5 m^3/s	25% underestimate	33% underestimate	10% underestimate
Kerb Inlet Only	> 0.5 m^3/s	45% underestimate	33% underestimate	OK
Combination with 1 m Grate	< 0.15 m^3/s	OK	OK	OK
Combination with 1 m Grate	0.15 to 0.5 m^3/s	5% overestimate	OK	OK
Combination with 1 m Grate	> 0.5 m^3/s	20% overestimate	20% overestimate	10% underestimate

Velocities, depths and other characteristics are obtained from normal depth calculations using the specified cross-section (from the overflow route cross-section data base), slope and roughness.
The HGL calculations associated with rational method in the urban stormwater drainage chapter of *Australian Rainfall and Runoff*, and those in steady state hydraulics programs such as HEC-2 and HEC-RAS, are at the second level. Several programs, mostly proprietary ones, offer full hydrodynamic modelling options using complex finite difference calculations. These can give the most accurate results with an experienced, hydraulically-knowledgeable operator, but can be subject to stability problems.

5.6.2 Pipe Design Calculations

In a design run, *DRAINS* determines pipe sizes and invert level positions by calculating the peak flows of hydrographs entering a pipe system and designing for these in a downwards pass, making certain assumptions. The method considers both minor and major storms of different average recurrence intervals. Pit sizes are also designed to keep overflows within safe limits defined in the overflow route data base.

The design procedure must be followed by analysis runs using the same design storms to simulate and display the performance of the system in detail. The designer can than assess whether this is satisfactory, and make further changes and re-runs to refine the system.

5.6.3 Basic Hydraulic Calculations

In *DRAINS,* the now obsolete basic hydraulic model provided a conservative procedure for tracing hydraulic grade lines through drainage systems, working upwards from tailwater levels at the outlet at each calculation time step. At each time step in an analysis, this model made a pass downwards through the drainage system, determining flows into pits, possible bypass flows and the flows along pipes. It then retraced this path from a specified tailwater level at the system's outfall, determining hydraulic grade lines and water levels in pits. Allowance was made for pipe friction and pit pressure changes, and both part-full and full-pipe flows were modelled. The possibility of water upwelling from pits due to the flow capacity of the downstream pipe system being exceeded was also considered. With this model, *DRAINS* used a hydraulic engine from the PIPES program to model pressurised flows. It switched to this when pipes surcharged, going from part-full to full pipe flow, and handled the complex timing and flow volume transitions involved in transferring between calculation methods.

5.6.4 Unsteady Flow Calculations in Standard and Premium Hydraulic Models

As noted in Section 4.2.7, the unsteady hydraulic method applied in the standard and premium hydraulic models is quite different to method used by the basic hydraulic model. The unsteady model in *DRAINS* solves the full St. Venant equations of momentum and continuity using an implicit finite difference scheme with a staggered H, Q grid. This solution scheme is widely used in other software such as SWMM. Links are divided into an odd number of reaches (1, 3, 5, etc.) with *DRAINS* automatically determining a suitable number to use. When *DRAINS* reports the flow in a link it is referring to the flow calculated at this central grid point.

The method applies the Saint Venant Equations for conservation of mass and momentum in unsteady flow:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad \text{(Continuity or Mass)} \qquad \text{... (Equation 5.17)}$$

$$\frac{1}{gA}\left(\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(Q^2/A\right) \right) + \frac{\partial H}{\partial x} + S_f = 0 \quad \text{(Momentum)} \qquad \text{... (Equation 5.18)}$$

where
Q is flow, A is cross-sectional area,
H is water surface level, t is time,
x is distance along a channel, g is gravitational acceleration,
S_f is friction slope

The calculation procedure applied in *DRAINS* involves the solution of these equations to determine H and Q at all points in a system at each time step of the simulation. Equations are gathered into a matrix and solved, allowing for different types of boundary conditions imposed by flows entering pipe and channel systems, downstream tailwater levels and the hydraulic features at on-grade and sag pits, headwalls and other features.

In the premium hydraulic model, pipes, open channels and overflow routes are all modelled by the same procedures, based on open channels. Closed pipes can be treated as being open by using a Priessmann slot (Figure 5.28). Each link has a representative cross-section, so it is necessary to divide open channels and overflow routes into separate links where their geometric characteristics change.

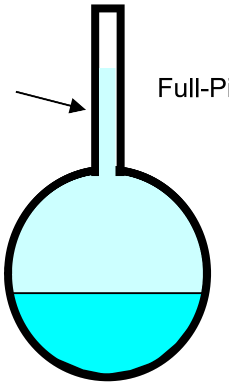


Figure 5.28 Priessmann Slot for Modelling Pipes as Open Channels

At sag pits there will be two HGL levels, one describing the water level in the ponded runoff at the surface and the other describing the pipe HGL.

Calculations for outlet weirs from sag pits, detention basins, headwalls, and culverts use tables of elevation vs. discharge.   To cover the situation where tailwater levels below these controls are high, in the premium hydraulic model, *DRAINS* uses the Villemonte equation to modify the table if the downstream water level is above the weir crest (the level in the table at which Q=0). The Villemonte equation allows for submergence of the weir:

$$Q = C_{df} \,.\, C_d \,.\, {}^2/_3 \;\; (2g)^{0.5} .\, b \,.\, h^{1.5} \qquad \text{…(Equation 5.19)}$$

where Q is the flowrate (m^3/s),
C_d is the discharge coefficient (dimensionless),
g is acceleration due to gravity (9.80 m/s^2),
b is the effective width of the weir (m),
h is the effective head (m), and
C_{df} is a drowning factor, equal to $C_{df} = A\,(1 - (h_2/h_1)^{1.5})^n$
where A and n are coefficients,
h_1 is the upstream measured water level above the weir, and
h_2 is the downstream measured water level below the weir.

At headwalls and culverts the flow capacity is often limited by inlet control. All flow models in *DRAINS* use the equations for culverts and headwalls presented in this manual to check for inlet control at these structures. *DRAINS* also allows for the specified inlet capacity relationships at on-grade pits as long as these are not submerged.

For sag pits a truncated inverted pyramid shape is assumed, with the base length at the gutter invert level being half that at the overflow level. Alternatively, the user can specify a table of elevation versus surface area. With the premium hydraulic model, users must provide a weir control specification in the Overflow Route property sheet and water can rise above the maximum ponded level. With the standard and basic hydraulic models water does not rise above the maximum ponded level, rather any water above this level is assumed to immediately spill into the overflow route.

5.6.5   Pipe Friction Equations

For circular pipes, you have a choice of the Colebrook-White Equation or Manning's Formula.
The Colebrook-White Equation employs the formula:

$$V = -0.87.\sqrt{2g \cdot D \cdot S} \cdot \log_e\left(\frac{k}{3.7 \cdot D} + \frac{2.51 \cdot \upsilon}{D \cdot \sqrt{2g \cdot D \cdot S}}\right) \qquad \text{.... (Equation 5.20)}$$

where g is gravitational acceleration (m/s^2), generally 9.80 m/s^2 at sea level,
D is diameter (m),
S is energy line slope (m/m),
k is pipe wall roughness (mm), sometimes termed e, and

υ is the kinematic viscosity (taken as 1.14 x 10^{-6} m^2/s at 15°C).

The pipe wall roughness values in Table 5.21 are recommended by Hydraulics Research (1983) and the Standards Association of Australia (1978). Values for other materials are also given in these publications.

Table 5.21 Recommended Colebrook-White Roughnesses, k

Pipe Material	**Hydraulics Research Recommendations: k values** (mm) **for pipe condition:**			**SAA Recommendations: for concentrically-jointed, clean pipes**
	Good	**Normal**	**Poor**	
Concrete				
Precast, with 'O' Ring Joints	0.06	0.15	0.6	0.03 to 0.15
Spun precast, with 'O' Rings	0.06	0.15	0.3	
Monolithic construction, against steel forms	0.3	0.6	0.15	
Monolithic construction, against rough forms	0.6	1.5	-	
Asbestos Cement		0.015-0.03		0.015 to 0.06
UPVC				
Chemically-cemented joints		0.03		0.003 to 0.015
Spigot and Socket Joint		0.06		

Manning's Equation is

$$V = \frac{1}{n} . R^{0.667} \ S^{0.5} \qquad \text{.... (Equation 5.21)}$$

in which V is velocity (m/s),
n is a roughness coefficient
R is the cross-section hydraulic radius (m) (= area / wetted perimeter, A/P), and
S is longitudinal slope (m/m).

5.6.6 Pit Pressure Changes

(a) General

The head losses and changes to the energy grade line and hydraulic grade line at pits and junctions are extremely important in determining pipe system behaviour accurately. Figure 5.29 shows how these are represented by two functions of the pit outlet velocity V_o, for full-pipe flow.

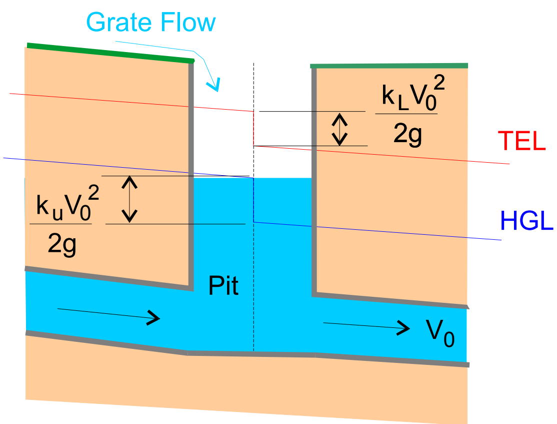


Figure 5.29 Pit Energy Losses and Pressure Changes

The TEL will drop by the amount of the head loss for the pit, which can be expressed as:

$$h_L = k_L \cdot \frac{V_o^2}{2g}$$ …(Equation 5.22)

where h_L is head loss (m),
k_L is the head loss coefficient (dimensionless),
Vo is the full-pipe velocity in the outlet pipe from the pit (m/s), and
g is acceleration due to gravity (9.80 m/s^2).

More importantly for design, the pressure change is given by:

$$h_u = k_u \cdot \frac{V_o^2}{2g}$$ … (Equation 5.23)

where h is head loss (m), and
k_u is the head loss coefficient (dimensionless, also expressed as K_u).

Generally k_u is positive, with the HGL dropping down, but it is sometimes negative, with the line rising due to the downstream pipe having a larger diameter and slower velocity than the upper one. This has been termed 'static regain'.

It is assumed that head losses and pressure changes take place at the centre of the pit, while actual losses occur mainly in the outlet pipe just downstream of the pit. Where significant turbulence occurs in the pit, the water level may be higher than the incoming HGL. A higher factor k_w may be used in place of k_u to establish water levels where information on these factors is available. A different factor to the main branch k_u may also be applied to side branches.

There are an infinite number of combinations of factors affecting the magnitudes of k_L and k_u. These include relative flows in upstream flows, the local inlet and the downstream pipe, the relative diameters of upstream and downstream pipes, the angles of the pipes and the positions of their obverts and inverts, the presence of benching in a pit, the degree of submergence of the pit, and the pit shape. The 'Missouri Charts' (Sangster et al., 1958) are the primary source of information on pressure changes, with the paper by Hare (1983) being useful. However, there are many cases that are not covered by these and other references. The *Queensland Urban Drainage Manual* (Queensland Department of Natural Resources and Water, 2008) provides a good coverage of available information on this topic, together with a rather complex procedure for selecting pressure change coefficients using selected Missouri and Hare Charts.

There are theoretical relationships for pressure changes based on conservation of momentum calculations (Hare and O'Loughlin, 1991), but these do not cover all cases. 1.5 is given as a default value for k_u in the *DRAINS*' Drainage Pit property sheet.

A review of pit pressure changes and head losses (O'Loughlin and Stack (2002) discussed possible algorithms or methods that might be used to determine pressure changes. Two procedures, the Mills equation and the QUDM Method described below have been implemented.

(b) Mills Equation

In the *DRAINS* **Run** menu, there is the option named **Revise Pit Loss Coefficients**. This alters the coefficients using an adaptation of an approximate method devised by Mills (Mills and O'Loughlin, 1982-98). Basically, this is

$$k_u = 0.5 + 2.\left(\frac{Q_m}{Q_o}\right) + 4.\left(\frac{Q_g}{Q_o}\right)$$ …(Equation 5.24)

where Q_m is the inflow from upstream pipes that are misaligned,
Q_a is the aligned flow,
Q_g is the grate inflow, and
Q_o is the outflow, equal to $Q_m + Q_a + Q_g$

DRAINS assumes that pipes at angles of 45^o or more to the outlet pipe are misaligned. A value of 0.5 is subtracted if the outlet pipe diameter is larger than that of any of the inlet pipes. For a drop pit, the incoming flow from a pipe may be classed as grate flow if the inlet pipe's invert is located above the pit water level. Mill's assessment of misalignment of incoming pipes cannot be judged automatically by *DRAINS*.

This procedure is implemented by performing a Design run, and then choosing the option **Revise Pit Loss Coefficients** in the **Run** menu. This changes the original coefficients, using the flows determined in the previous design run, thus overcoming the difficulty of having to estimate k_u factors roughly in advance when exact flows are not known. The procedure can also be implemented after an Analysis run. This may lead to somewhat different coefficients because the relative values of Q_m, Q_o and Q_g may be different. The process can be repeated to refine the result. It must be noted that this procedure is approximate and may give poor estimates for some situations. The estimated coefficients need to be checked and corrected where necessary.

(c) The QUDM Method

As noted above, the *Queensland Urban Drainage Manual* (Queensland Department of Natural Resources and Water, 2008) contains a procedure that guides a designer through a set of Missouri and Hare Charts, enabling k_u, and if appropriate water level factor k_w and branch pipe factor k_l to be determined. This procedure has been outlined in Section 3.4.4, with the related spreadsheet outputs for rational method calculations being set out in Section 3.5.4. It involves a search through several graphs based on criteria set out in Appendix 4 in QUDM Volume 2. In complex cases where there is no appropriate chart, an estimate from the momentum equations described by Hare and O'Loughlin (1991) is used.

The procedure in *DRAINS* allows k_u coefficients to be determined automatically, without consideration of all circumstances. It is therefore important to carry out checks using the appropriate charts.

(d) Part-Full Pipe Pressure Changes

Information on part-full pit pressure changes is sketchy, because researchers have concentrated on the full-pipe flow case that is more likely to occur at peak flows through pipe systems. The treatment of part-full pressure changes has varied in *DRAINS*, as additional information has become available, and the needs of the hydraulic modelling procedures have changed.

Currently, in the standard and premium unsteady flow models, a constant pit pressure change coefficient k_u is assumed to apply to both full-pipe and part-full flows. This is assumed in the interests of stability of calculations, and is likely to conservatively overestimate changes.

5.6.7 Tailwater Levels

DRAINS calculations require a downstream boundary condition, with the levels of the receiving water being specified in advance. This can be a level specified by the user in the Outlet Node property sheet, or one assumed from conditions at the outlet. For steep pipe slopes (supercritical flow), it will be assumed to be the normal depth, and for mild pipe slopes (subcritical flow), it will be assumed to be the critical depth in the standard and premium hydraulic models.

Setting an appropriate tailwater level can be difficult. The For a pipe system discharging to a free water body such as a lake, large stream or the sea, the tailwater will be the water level occurring in this body at the time that the storm passing through the drainage system occurs. Using *DRAINS*, you must determine the most likely level coinciding with the storm for normal design or analysis, and high values such as high tide levels in marine waters for modelling of extreme conditions. The *DRAINS Utility Spreadsheet* includes a procedures for modelling a tailwater level that changes with time during a storm event.

Where the drainage system catchment is significantly smaller than the catchment of the larger, receiving water body, it is likely that the rainfalls over the two catchments will differ in intensity and timing. The estimation of appropriate events to define critical conditions requires some statistical skill and knowledge of local storms. Where the system being analysed is a pipe system discharging into a larger pipe or trunk drain, the level to be selected should be the higher of the receiving pipe's HGL or receiving open channel's water surface level at the junction. Hydraulic calculations may be necessary to establish these levels, but valid results cannot be obtained unless appropriate tailwater levels are used.

5.7 Hydraulics of Open Channels

The basic hydraulic method, now obsolete, projected water surface upstream along open channels using the standard step method (Chow, 1959, Henderson, 1966 and other texts) for subcritical flows, For supercritical flows, the critical depth line is traced, and water depths are assumed not to fall below this, providing a conservative estimate of depths.

The unsteady flow procedures applied to open channels in the standard and premium model are the same as those for pipes, outlined in Section 0, solving the mass and momentum flow equations. Manning's equation is used to define channel friction. Suggested roughness values for channels are given in Table 5.22. More comprehensive lists are given in texts and manuals on open channel flow and in Chapter 4 of *Australian Rainfall and Runoff*, 1987.

Table 5.22 Manning's Roughness Coefficients, n

Surface Type	Suggested n Values
Concrete Pipes or Box Sections	0.012
Concrete (trowel finish)	0.012 - 0.015
Concrete (formed, without finishing)	0.013 - 0.018
Concrete (gunite)	0.016 - 0.020
Bricks	0.014 - 0.016
Pitchers or Dressed Stone in Mortar	0.015 - 0.017
Random Stones in Mortar or Rubble Masonry	0.020 - 0.035
Rock Lining or Rip-Rap	0.025 - 0.030
Earth (clear)	0.018 - 0.025
Earth (with weeds or gravel)	0.025 - 0.035
Rock Cut	0.035 - 0.040
Short Grass	0.030 - 0.035
Long Grass	0.035 - 0.050

Various energy losses can occur at changes or transitions in channel sections. These are covered by contraction and expansion losses, typically 0.1 and 0.3, respectively. These factors allow for energy losses due to changes in cross-sections and velocities through these. If the velocity increases or decreases between two cross-sections, the HGL is lowered by a coefficient multiplied by the difference in velocity heads at the two sections. For example, if the upper and lower sections are labelled 1 and 2, the losses for the two cases will be:

$$\text{Contraction coefficient}\ .\ \left(\frac{V_2^2}{2g}-\frac{V_1^2}{2g}\right) \qquad \text{… (Equation 5.25)}$$

$$\text{Expansion coefficient}\ .\ \left(\frac{V_1^2}{2g}-\frac{V_2^2}{2g}\right) \qquad \text{… (Equation 5.26)}$$

Table 5.23, taken from the HEC.RAS Version 3.1 *Hydraulic Reference Manual* (2002), Chapter 3, gives values of coefficients.

Table 5.23 Contraction and Expansion Coefficients for Open Channel Flows

Situation	Contraction Coefficient	Expansion Coefficient
No transition Loss	0.0	0.0
Gradual Transitions	0.1	0.3
Typical Bridge Sections	0.3	0.5
Abrupt Transitions	0.6	0.8

5.8 Detention Basin Hydraulics

5.8.1 Routing

DRAINS performs accurate reservoir routing calculations for detention storages, employing the height-storage-outflow relationship and initial storage supplied by the user. The method used is an extension of the Modified Puls Method, based on the continuity equation applied over a time step, Δt,

$$\frac{I_i + I_{i+1}}{2} - \frac{Q_i + Q_{i+1}}{2} = \frac{S_{i+1} - S_i}{\Delta t} \qquad \text{... (Equation 5.27)}$$

Average of Inflow rates at the start of a period, I_i and at the end, I_{i+1}	Average outflow rate over the period	Rate of change of storage

together with a relationship linking outflow rates with corresponding storages for various water levels in a reservoir or basin.

Reservoir routing procedures work on a finite-difference step-by-step procedure, working through the time periods from the start of a known inflow hydrograph. Conditions at the beginning of each time step are known, and relationships are used to derive conditions at the end. There are many ways of setting up these calculations, both direct and iterative, but the following way, used in ILSAX, is probably the simplest.

Equation 6.32 can be rearranged so that the known terms are placed on the left hand side (LHS):

$$I_i + I_{i+1} - Q_i + \frac{2S_i}{\Delta t} = Q_{i+1} + \frac{2S_{i+1}}{\Delta t} \qquad \text{... (Equation 5.28)}$$

Inflow values I_i, I_{i+1}, etc. are known in advance, and outflow Q_i and storage S_i at the beginning of each period are known. Routing procedures estimate values for Q_{i+1} and S_{i+1} by various methods of graphical or numerical interpolation.

DRAINS applies this procedure at each time step, but also allows for tailwater effects that might alter the elevation-discharge (or height-outflow) relationship.

A height-storage-outflow relationship can be developed from:

(a) a height-storage relation, derived from contour information on the topography of the storage area,

(b) a height-outflow relation, constructed from the hydraulic relationships for the outlet structures for the reservoir, which can be orifices, pipe systems, weirs, or combinations of these.

DRAINS allows for separate height-outflow relationships for low- and high-level outlets of the type shown in Figure 5.30. Routing is performed with a combined relationship, but outflows via high-level outlets, such as diversion weirs, can be directed out of the system or to reaches other than the one immediately downstream.

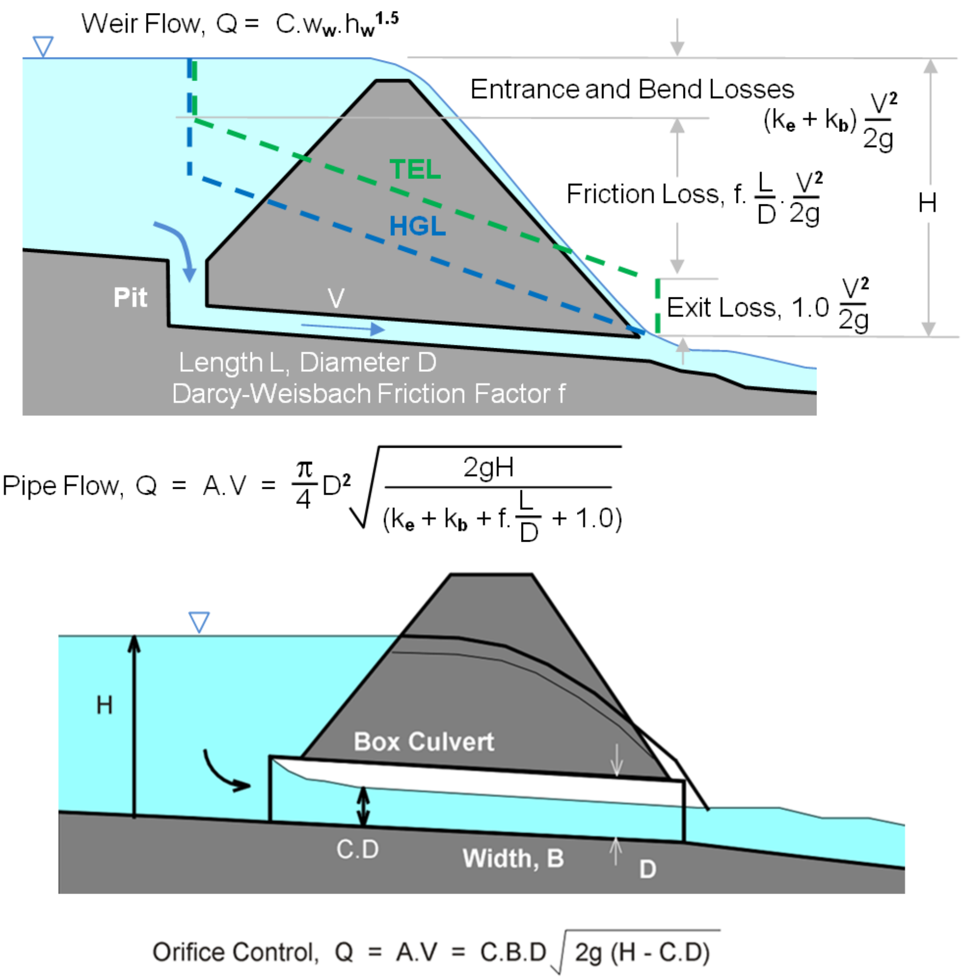


Figure 5.30 Detention Basin Outlets

5.8.2 Overflows from Basins

Low-level outlets from basins consist of culvert or drop pit pipe systems. The outflow rate for these is dependent on the headwater and tailwater levels, and energy losses through the pipe system. Height-outflow (or depth-discharge) relationships for various kinds of outlets are given in textbooks and manuals on hydraulics. The equations shown in the box below are used for calculating height-outflow relationships in *DRAINS* for detention basins, culverts and headwalls.

Equations for Determining Height-Outflow Relations used in the Detention Basin, Culvert and Headwall Calculations

Outlets with Circular Cross-Sections

These depend on the threshold level, TH, which is usually the invert level at the upstream end of the outlet pipe or culvert (m AHD), and pipe diameter D (m).

For (HW - TH) < 0.8 D, the flowrate for Inlet Control is:

$$Q_i = N_c \,.\, 1.50 \,.\, (S_c/40)^{0.05} \,.\, (HW - TH)^{1.9} \,.\, D^{0.6} \qquad \text{... (Equation 5.29)}$$

(inlet control, unsubmerged inlet, Henderson, 1966)

For 0.8 D < (HW - TH) < 1.2 D,

$$Q_i = N_c \,.\, 1.38 \,.\, (S_c/40)^{0.05} \,.\, (HW - TH)^{1.5} \,.\, D \qquad \text{… (Equation 5.30)}$$

(inlet control, unsubmerged inlet, Henderson, 1966), and

For (HW - TH) > 1.2 D,

$$Q_i = N_c \,.\, 1.62 \,.\, (HW - TH)^{0.63} \,.\, D^{1.87} \qquad \text{… (Equation 5.31)}$$

(inlet control, submerged inlet, Boyd, 1986)

The flowrate for Outlet Control is:

$$Q_o = N_c \,.\, \frac{\pi}{4} \,.D^2 \,.\, ((HW - TW) \,.\, 2g \,/\, (k_e + k_b + \text{Factor} + 1))^{0.5} \qquad \text{…(Equation 5.32)}$$

(outlet control, full pipe flow)

The outflow rate, Q (m^3/s), corresponding to level in the basin or headwater level, HW (m AHD), is the lesser of the calculated Q_i and Q_o values. Parameters used in the four equations are:

N_c is the number of parallel conduits,
L_c and S_c are the conduit length (m) and slope (%),
g is acceleration due to gravity, taken as 9.80 m/s^2,
TW is the higher of :
(a) the tailwater level downstream of the outlet (m AHD), and
(b) a level half way between the outlet obvert level, equal to (TH - S_c . L_c + D) and the level of the critical depth of the flow at the pipe outlet, calculated from:

$$d_c = D \,.\, \left(\frac{Q}{4.038 \cdot D^{2.5}}\right) 0.287 \quad \text{for} \quad \frac{d_c}{D} >= 0.82 \qquad \text{… (Equation 5.33)}$$

and

$$d_c = D \,.\, \left(\frac{Q}{3.005 \cdot D^{2.5}}\right) 0.510 \quad \text{for} \quad \frac{d_c}{D} < 0.82. \qquad \text{… (Equation 5.34)}$$

Since Q is not known exactly when the tailwater level is being established, an iterative procedure must be used In the above equations.

k_e is the entrance loss factor,
k_b is the total of other loss factors, e.g. at bends, and
Factor is a friction factor. If Manning's Equation is used with a roughness n, it is

$$n^2 \,.\, L_c \,.\, 2g \,.\, \left(\frac{D}{4}\right)^{-4/3} \qquad \text{… (Equation 5.4)}$$

If the Colebrook-White Equation is used, the Factor is $f.\ \frac{L_c}{D}$, where f is the Darcy-Weisbach friction factor. This can be obtained using an initial value given by the Swamee-Jain equation:

$$f = 1.325 / (\log_e(k/(3700 . D) + 5.74 / N_R^{0.9}))^2 \qquad \text{… (Equation 5.35)}$$

and iterations using the Colebrook-White Equation:

$$f = 1.325 / (\log_e(k/(3700 . D) + 2.51 / (N_R.f^{0.5})))^2 \qquad \text{… (Equation 5.5)}$$

in which,

k is the Colebrook-White wall roughness height (mm),
N_R is the Reynolds Number of the flow (This is unknown when calculations are performed, but it can be estimated roughly as:

$$\frac{V \cdot D}{\upsilon} = \frac{Q_i}{\frac{\pi}{4} \cdot D^2} \cdot \frac{D}{\upsilon} \qquad \text{… (Equation 5.37)}$$

V is the velocity of flow (m/s), and υ is the kinematic viscosity of water (1.14 x 10^{-6} m^2/s at 15°C). Note that the flowrate is assumed to be to be the inlet flow estimate and the pipe is assumed to be flowing full. This is not exact, and an iterative procedure should be used. However, the value of f is insensitive to the N_R used, and this approximation should be adequate.)

Outlets with Rectangular Cross-Sections

These are based on the threshold level TH (m AHD), usually the invert at the upstream end of the culvert, and the height of the culvert, H (m).

If (HW - TH) < 1.35 H, the flowrate for Inlet Control is:

$$Q_i = Nc . 1.70 . (HW- TH)^{1.50} . B \qquad \text{… (Equation 5.38)}$$

(inlet control, submerged inlet, Boyd, 1986)

If (HW - TH) ≥ 1.35 Height of Culvert:

$$Q_i = Nc . 2.20. (HW- TH)^{0.61} . H^{0.89} . B \qquad \text{… (Equation 5.39)}$$

(inlet control, submerged inlet, Boyd, 1986)

The flowrate for Outlet Control is:

$$Q_o = Nc . H . B . ((HW - TW) . 2g / (k_e + k_b + \text{Factor} + 1))^{0.5} \qquad \text{… (Equation 5.40)}$$

(outlet control, full pipe flow)

As for circular pipes, the outflow rate, Q (m^3/s), corresponding to level, HW, is the lesser of the calculated Q_i and Q_o values. B is its breadth or width of the conduit (m), and the other factors are as described above.

In the calculations concerning tailwater, the critical depth is determined as:

$$d_c = \left(\frac{Q^2}{g \cdot B^2}\right)^{0.333} \qquad \text{… (Equation 5.41)}$$

In the equations for finding the friction factor, diameter D is taken to be 4 times the hydraulic radius (m), equal to:

$$\text{Area / Wetted Perimeter} = \frac{H \cdot B}{2(H + B)} \qquad \text{… (Equation 5.42)}$$

In most cases, *inlet control* will govern, with the greatest restriction on flow capacity occurring at the culvert entrance. However, in some cases outlet *control* will apply, with the cause being high tailwater levels, or friction in relatively long and flat culverts.

High-level outlets such as weirs and slots are usually governed by the weir equation:

$$Q = C \cdot w \cdot h_w^{1.5} \qquad \text{.... (Equation 5.6)}$$

where Q is the outflow rate (m^3/s),
C is a weir coefficient, depending on the weir shape, roughness and length of the weir crest in the direction of flow,
w is the width of the weir (m), at right angles to the flow direction, and
h_w is the depth of water in the basin above the weir sill or crest.

Laurenson and Mein (1990) provide the weir coefficients shown in Figure 5.31. Further information can be obtained in the US Federal Highway Administration HDS-5 manual (Normann et al., 2005).

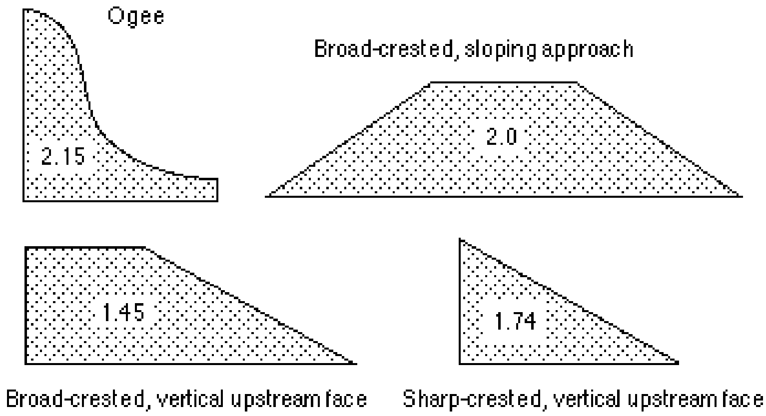


Figure 5.31 Weir Coefficients

5.8.3 On-Site Stormwater Detention

DRAINS is set up to model on-site stormwater detention (OSD) storages of the type shown in Figure 5.32, including high-early discharge (HED) systems, as shown in Figure 5.33. These can provide a considerable reduction of the storage needed to limit outflows to a prescribed limit.

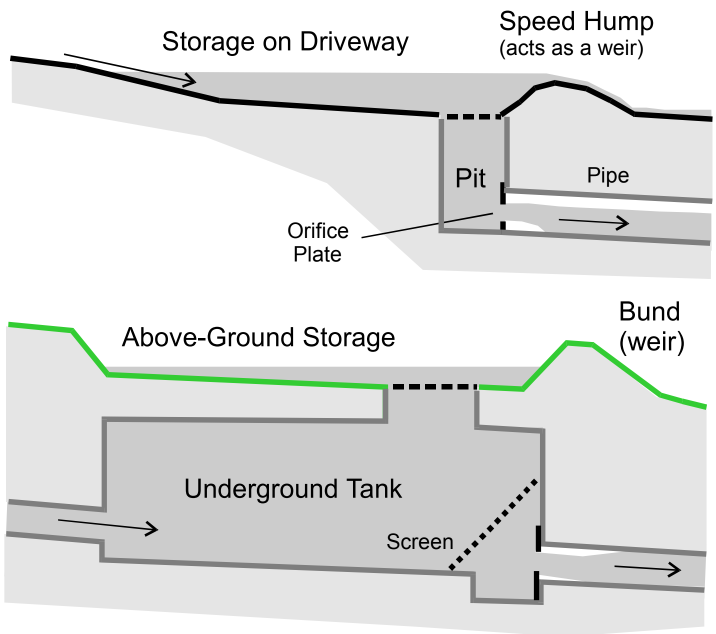


Figure 5.32 On-Site Detention (OSD) Storages

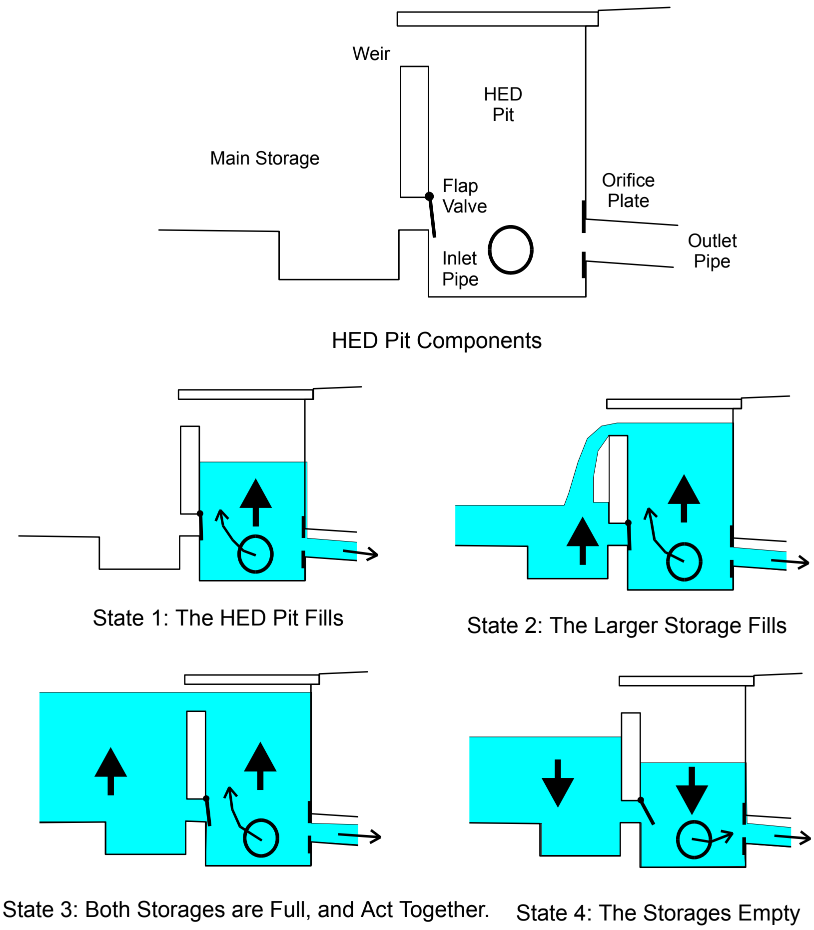


Figure 5.33 A High Early Discharge (HED) Pit

OSD storages are usually controlled by circular orifices with the discharge equation being:

$$Q = C_c \, . \, \frac{\pi}{4} \, d^2 \, . \, (2gh)^{0.5} \qquad \text{… (Equation 5.7)}$$

where C_c is a contraction coefficient, taken as a constant of 0.6 in *DRAINS*,
d is the orifice diameter (m),
g is the acceleration due to gravity (m/s^2), and
h is the height from the water surface to the centre of the orifice (m).

5.8.4 Infiltration

The second panel on the detention basin property sheet (Figure 2.37) displays data that can be used to model stormwater infiltration out of a storage that has a permeable base and/or permeable sides. The calculations involved are simple; the exposed surface of the storage at any time is multiplied by the hydraulic conductivity to define an outflow. The greater the depth in the storage, the larger the infiltration rate. Allowance is made for storages having permeable or impermeable floors and walls.
Infiltration procedures are discussed in detail in Argue, J.R. (editor) (2004) *WSUD: Basic Procedures for 'Source Control' of Stormwater*, University of South Australia Water Resources Centre, Adelaide. Indicative values of hydraulic conductivity (p. 44) are given in Table 5.24. Specific values for a site can be obtained from on-site tests and modified using factors provided in the above publication.

Table 5.24 Hydraulic Conductivities for Infiltration Calculations

Soil Type	Hydraulic Conductivity
Sandy soil	> 5 x 10^{-5} m/s
Sandy clay	between 1 x 10^{-5} and 5 x 10^{-5} m/s
Medium clay and some rock	between 1 x 10^{-6} and 1 x 10^{-5} m/s
Heavy clay	between 1 x 10^{-8} and 1 x 10^{-6} m/s
Constructed clay	< 1 x 10^{-8} m/s

5.9 Culvert and Bridge Hydraulics

5.9.1 Culverts

There are two meanings to the word, culvert. The first is a long pipe; the second is a pipe, usually short, constructed to allow flows in streams and artificial open channels to pass under road and railway embankments. The culvert component in *DRAINS* models the latter case. The first type of conduit should be modelled as a channel, or if storage and overflows are important, as a detention basin.

Culverts convey flows in pipes or rectangular conduits that through road embankments, usually obstructing flows by reducing the available waterway areas. Upstream water levels are raised, creating a headwater level higher than the water levels occurring under unobstructed flows. Downstream levels are lower, since flow emerges rapidly from the culvert, creating supercritical flow conditions until a hydraulic jump occurs. Several procedures are available for the design of culverts and analysis of their behaviour. In *DRAINS* the sets of equations presented by Henderson (1966) and Boyd (1986) given in Section 5.7 are used to determine the headwater levels occurring with a given flowrate and downstream tailwater level at each calculation time step. These equations allow for inlet control, where the constriction at the opening of the culvert is the determining factor, and for outlet control, where a high tailwater level and significant head losses make the conduit flow full.

In *DRAINS,* the flowrate and the downstream water level at each time step are established, and the corresponding headwater level is determined using the above equations. When either of two equations can be used because there are two possible states of flow, the equation giving the highest headwater level is selected.

A considerable amount of information on road culverts is available from the US Federal Highway Administration in manuals and software available at www.fhwa.dot.gov/bridge/hyd.htm. Mays (2001) also provides considerable information on culverts.

5.9.2 Bridges

Bridge hydraulics is particularly complicated because it is necessary to allow for the transitions from a broad channel cross-section to a constricted bridge cross-section and back to a channel section. The bridge abutments, piers and possibly the deck can all obstruct flows. Hydraulic expertise is required to interpret results.

The U.S. Federal Highway Administration has published methods by Bradley (1970) which have been used in the AUSTROADS waterway manual (1994). More extensive procedures are incorporated in the HEC-RAS computer program (Hydrologic Engineering Center, 1997). You are referred to these references for further details. *DRAINS* covers relatively simple bridge layouts. Use of HEC-RAS is recommended for complex arrangements involving multiple openings and broad channel cross-sections.

DRAINS uses the AUSTROADS procedures to define the afflux or rise in upstream water level caused by a bridge constriction. It does this at each calculation time step, for the current flowrate and downstream water level. As with culverts, allowance is made for possible overtopping and submergence of the bridge deck, treating this as a weir. Any overflows are added to the flows through the bridge opening occurring at the same time.

5.10 File Formats

5.10.1 General

This section provides some notes on file formats, as a guide to persons exchanging data between *DRAINS* and other programs.

5.10.2 Drawing File Formats

DRAINS can import and export graphical data in DXF format. As shown in Figure 5.34, this is an ASCII format, which can be edited on a text editor.

5.10.3 GIS File Formats

(a) GIS Systems

Geographic Information System (GIS) programs combine a mapping facility with a data base of information on the spatial position of components, such as drainage pits and pipes, and on their other attributes, such as pipe diameters. Objects displayed in different ways, according to one or more of their attributes. Maps can be produced on paper or can be inspected electronically.

The most common products used in Australia are ArcView (produced by ESRI (www.esri.com) and MapInfo (produced by MapInfo Corporation (www.mapinfo.com), but Autodesk Map (www.autodesk.com) and Intergraph (www.intergraph.com). There are also a number of companies that provide systems based on the main types of software. GIS file structures can be complex. In MapInfo, two file types, with suffixes MID and MIF, are required, so that 12 files are generated in a transfer from *DRAINS*.

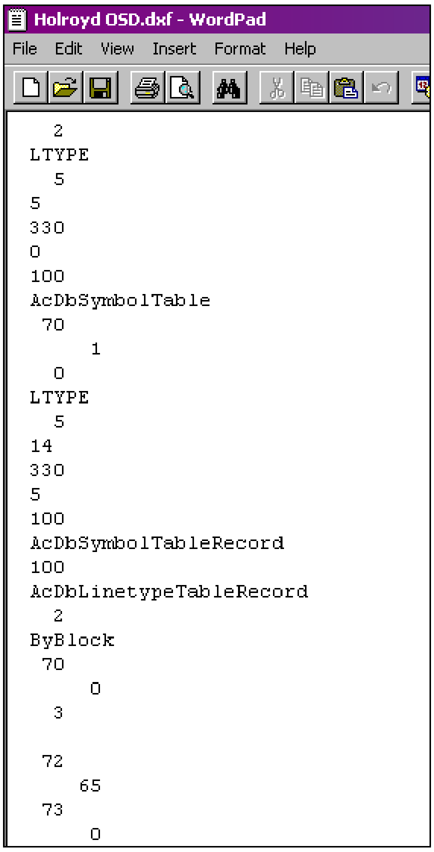


Figure 5.34 ASCII File in an Editor

(b) ESRI (ArcView) Formats

ArcView stores spatial information in various formats. The data imported or exported by *DRAINS* are in a set of three binary files, all having the same initial part of their name:

- a SHP file, the main file defining a number of records for shapes (points, lines, poly-lines or polygons), defined by the coordinates of their vertices,
- a SHX file acting as an index to the records in the main file,
- a DBF file containing a DBASE table of attributes associated with each record.

To specify an object such as a pipe fully, a set of these three files is established. The transfers to and from *DRAINS* involve files for up to six objects - pits, sub-catchments, pipes, overflow routes, survey data on ground levels along pipe routes and positions of other services, a total of 18 files, plus a DXF file containing the background to the drainage system, which can be transferred at the same time.

For nodes, a table with the following 13 headers for columns or 'fields' are required:

1	Shape	the nature of the object (point)
2	Name	any name up to 10 characters
3	DRAINSid	an internal number used by *DRAINS* to connect nodes and link this must be kept blank
4	Type	type of node: 'OnGrade', 'Sag' or 'Node'
5	Family	the pit family, corresponding to a family in the pit data base in the *DRAINS* model to which the data is being transferred, or 'N/A'
6	Size	a pit size within the nominated pit family, or 'N/A'
7	PondingVol	the volume of water that can pond over a sag pit (m^3)
8	Ku	the pit pressure change coefficient (Use 'N/A' for simple nodes)
9	SurfaceEl	the surface elevation at the node (m)
10	PondDepth	a Colebrook-White or Manning's roughness coefficient
11	BaseFlow	any constant baseflow (m^3/s) originating at the node
12	BlockFactr	a blocking factor to be applied at pits ('N/A' is used for nodes),
13	BoltDnLid	a 'Yes', 'No' or 'N/A' as to whether there is a bolt down lid

In a shapefile exported from *DRAINS*, there may also be:

Hgl_XXXXX - optionally, one or more HGL levels taken from a series of runs for. Different storms. 'XXXXX' takes different values.

For pipes, a table with the following 12 headers for columns or 'fields' are required:

1	Shape	the nature of the object (line or poly-line),
2	Name	any name up to 10 characters
3	*DRAINS*id	an internal number used by *DRAINS* to connect nodes and links - this must be kept blank
4	Length	the pipe length (m),
5	UpstreamIL	the invert level at the upstream end of the pipe (m),
6	DownStrmIL	the downstream invert level (m),
7	Slope_pct	the pipe slope (%),
8	Type	the pipe type, which must correspond to a type in the pipe database of the *DRAINS* model to which the data is being transferred
9	NomDia	the nominal pipe diameter (mm) corresponding to diameters in the pipe type nominated
10	Roughness	a Colebrook-White or Manning's roughness coefficient
11	Status	'New' or 'NewFixed' or 'Existing'
12	NumPipes	the number of parallel pipes, usually 1

In a shapefile exported from *DRAINS*, there may also be:

Flow_XXXXX - optionally, one or more flowrates from different storms, designated by XXXXX,
V_XXXXX - optionally, one or more velocities from different storms, for example'50Yr'.
For information on the other four components, you can refer to the formats of exported ESRI files in the MIF files. Note that all numbers are exported as text and not as numbers. They will need to be converted in an ESRI program if the attributes are to be used as the basis for colour-coded thematic mapping.

(c) MapInfo Formats

MapInfo stores spatial information in a set of two ASCII files, both having the same initial part of their name:

- a MIF (MapInfo Interchange File) is the main file defining a format for data records associated with objects (points, lines or polygons) and the coordinates of the vertices of objects,
- a MID file containing the contents of a table of attributes associated with each object.

The data for nodes (pits) in the MID file is in a table with the following 12 headers:

1	Name	any name up to 11 characters
2	DRAINSid	an internal number used by *DRAINS* to connect nodes and links - this must be kept blank
3	Type	type of node: 'OnGrade', 'Sag' or 'Node'
4	Family	the pit family, corresponding to a family in the pit data base in the *DRAINS* model to which the data is being transferred, or 'N/A',
5	Size	a pit size within the nominated pit family, or 'N/A',
6	PondingVol	the volume of water that can pond over a sag pit (m^3)
7	Ku	the pit pressure change coefficient (Use 'N/A' for simple nodes),
8	SurfaceEl	the surface elevation at the node (m),
9	PondDepth	a Colebrook-White or Manning's roughness coefficient
10	BaseFlow	any constant baseflow (m^3/s) originating at the node
11	BlockFactr	a blocking factor to be applied at pits ('N/A' is used for nodes)
12	BoltDnLid	a 'Yes', 'No' or 'N/A' as to whether there is a bolt down lid

In a MID file exported from *DRAINS*, there may also be:

HGL_XXXXX - optionally, one or more HGL levels taken from a series of runs for. Different storms. 'XXXXX' takes different values, for example, '5 Yr'.

For pipes, the table includes the following 11 or more headers:

1	Name	any name up to 11 characters
2	DRAINSid	an internal number used by *DRAINS* to connect nodes and links - this must be kept blank
3	Length	the pipe length (m),
4	UpStreamIL	the invert level at the upstream end of the pipe (m),
5	DownStrmIL	the downstream invert level (m),
6	Slope_pct	the pipe slope (%),
7	Type	the pipe type, which must correspond to a type in the pipe database of the *DRAINS* model to which the data is being transferred
8	NomDia	the nominal pipe diameter (mm) corresponding to diameters in the pipe type nominated
9	Roughness	a Colebrook-White or Manning's roughness coefficient
10	Status	'New' or 'NewFixed' or 'Existing'
11	NumPipes	the number of parallel pipes, usually 1

In a MID file exported from *DRAINS*, there may also be:

Flow_XXXXX - optionally, one or more flowrates from different storms, designated by XXXXX,
V_XXXXX - optionally, one or more velocities from different storms.

For information on the other four components, you can refer to the formats of exported MapInfo files, reading the MIF file with a text editor.

Note that all numbers are exported as text and not as numbers. They will need to be converted in MapInfo if attributes are to be used as the basis for colour-coded plotting.

5.10.4 Spreadsheet File Formats

DRAINS transfers data to spreadsheet programs in the space-delimited ASCII format shown in Figure 5.35. This appears in cells when opened in a spreadsheet program, as shown in Figure 1.33.

```
Document - WordPad
File  Edit  View  Insert  Format  Help

PIT / NODE DETAILS                  Version 6
Name   Type  Family       Size  Ponding      Pressure     Surface      Max Pond     Base  Blocking     x       y      Bolt-down    id
                          Volume             Change       Elev (m)     Depth (m)    Inflow            Factor                       lid
                          (cu.m)             Coeff. Ku                 (cu.m/s)
Pit B.1      Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5      4.5   707.1 0.2    0      0.2    211.798      101.
Pit B.2      OnGrade      Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          0.5   707.0       0      0.2   227.558
Pit B.3      Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5      1.0   706.5 0.2    0      0.2    287.099      101.
Pit B.4      OnGrade      Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          0.5   706.1       0      0.2   290.690
Pit B.5      Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5      1.5   705.3 0.2    0      0.2    290.762      11.2
Pit B.6      OnGrade      Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          1.5   705.3       0      0.2   301.465
Pit B.7      OnGrade      Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          1.5   704.5       0      0.2   329.035
N.3    Node                          704.3        0           348.224      -3.153         244
N 4    Node                          703.5        0           373.740      -71.352        249
N 5    Node                          702.5        0           428.021      -103.363       250
N 7    Node                          701.4        0           524.055      -120.993       275
Outlet       Node                          699.5        0           627.512      -173.417       280
Pit C.1      Sag   Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel    5      4.5   706.8 0.2    0      0.2    212.647      7.63
Pit C.2      OnGrade      Qld. DMR Gully Pit, both, 0.25-2% grade   S Lintel          0.5   705.8       0      0.2   227.745
N 1    Node                          704.8        0           348.224      87.778         252
HW 2   Headwall                      0.5    704.2        0           348.224      12.620         269
N 0    Node                          703.4        0           352.399      -137.694       305

SUB-CATCHMENT DETAILS
Name   Pit or       Total Paved Grass Supp  Paved Grass Supp  Paved Grass Supp  Paved Grass Supp  Paved Grass Supp  Lag Time
       Node   Area  Area  Area  Area  Time  Time  Time  Length      Length      Length      Slope(%)    Slope Slope Rough Roug
              (ha)  %     %     %     (min) (min) (min) (m)   (m)   (m)   %     %     %                             (m)   %
Cat B.1      Pit B.1      0.7560      35.0  60.0  5.0   7     10    1
Cat B.2      Pit B.2      0.1320      85.0  15.0  0.0   3     4     0
Cat B.3      Pit B.3      0.5400      40.0  55.0  5.0   7     10    0
Cat B.4      Pit B.4      0.1040      85.0  15.0  0.0   3     4     0
Cat B.5      Pit B.5      0.6020      35.0  60.0  5.0   7     11    0
Cat B.6      Pit B.6      0.1680      85.0  15.0  0.0   4     5     0
Cat B.7      Pit B.7      0.3810      40.0  55.0  5.0   7     11    1
Cat 3 N.3    0.1600      0.0   100.0 0.0   0     5     0                                                 0
Cat 4 N 4    3.7550      30.0  70.0  0.0   13    20    0                                                 0
Cat 5 N 5    2.0050      10.0  90.0  0.0   18    25    0                                                 0
Cat 6 Cul 6 1.0700      0.0   100.0 0.0   0     20    0                                                 0
Cat 7 Basin 6      1.8700      5.0   90.0  0.0   15    25    0                                                 0
Cat 9 Bridge 9     4.1500      0.0   90.0  0.0   0     30    0                                                 0
Cat C.1      Pit C.1      0.9150      45.0  50.0  5.0   5     8     1

For Help, press F1                                                                                                  NUM
```

Figure 5.35 ***DRAINS*** **Spreadsheet Output displayed in an Editor**

5.10.5 TUFLOW TS1 File Formats

Using the **File → Export → Tuflow TS1 Files…** option described in Section 3.5.6, *DRAINS* can transfer calculated hydrographs to TUFLOW and other programs in the format shown in Figure 5.36, which can readily be imported into spreadsheet programs.

```
! File created from: C:\2007 DRAINS Files\Manual Example Files - March 2007
! Storm event:AR&R 100 year, 15 minutes storm, average 140 mm/h, Zone 1
! Timestep: 0.111111 min
! Number of timesteps: 853
! Number of catchments: 5
5,853
Start_Index,1,1,1,1,1
End_Index,853,853,853,853,853
Time (min),Cat 5,Cat 4,Cat 3,Cat 2,Cat 1
0.111,0.000,0.000,0.000,0.000,0.000
0.222,0.000,0.000,0.000,0.000,0.000
0.333,0.000,0.000,0.000,0.000,0.000
0.444,0.000,0.000,0.000,0.000,0.000
0.556,0.001,0.003,0.001,0.000,0.000
0.667,0.001,0.005,0.002,0.001,0.000
0.778,0.002,0.007,0.003,0.001,0.000
0.889,0.003,0.010,0.003,0.002,0.000
1.000,0.003,0.012,0.004,0.002,0.000
1.111,0.004,0.015,0.005,0.002,0.000
1.222,0.005,0.017,0.006,0.003,0.000
1.333,0.005,0.019,0.007,0.003,0.000
1.444,0.006,0.022,0.008,0.004,0.000
1.556,0.007,0.024,0.009,0.004,0.000
1.667,0.007,0.027,0.009,0.004,0.000
```

Figure 5.36 TUFLOW TS1 Output Displayed in an Editor

A. THE *DRAINS* VIEWER

A.1 Introduction

Written in a simpler style than the main manual, this appendix describes how to use of the *DRAINS* Viewer, which allows a checker to examine any *DRAINS* model submitted to them. It has been prepared for persons checking or reviewing *DRAINS* models, either internally within a design organisation, or as a council officer or private assessor. It also provides guidance to designers on choices to be made when setting up models and on information to be submitted for review.

Use of the free Viewer relieves reviewers of the need to check manually for numerical errors in tables or spreadsheets submitted for approval. A *DRAINS* model can be submitted to the reviewer as a **`.drn`** file with included results. The reviewer can then inspect the model using the *Viewer* and concentrate on the suitability of the selected inputs and the resulting flows and flood levels, knowing that results have been reliably calculated by *DRAINS*.

A.2 Setting Up and Running the Viewer

The free installation file named **`DrainsViewerSetup.exe`**can be obtained from Bob Stack on (02) 6649 8005 or bobstack@watercom.com.au. To install the *Viewer* on any PC running Microsoft Windows, run the file **exe** and follow the instructions that appear.

Once installed, the *DRAINS Viewer* can then be opened from the **Start** menu by selecting **Programs** and then **DrainsViewer**. The Main Window will then open, and after you have closed the introductory message, will appear as shown in Figure A.1. If needed, Help can be called from the **Help** menu, or by pressing the **F1** button. Options in the **View** menu can be used to alter the look of the model.

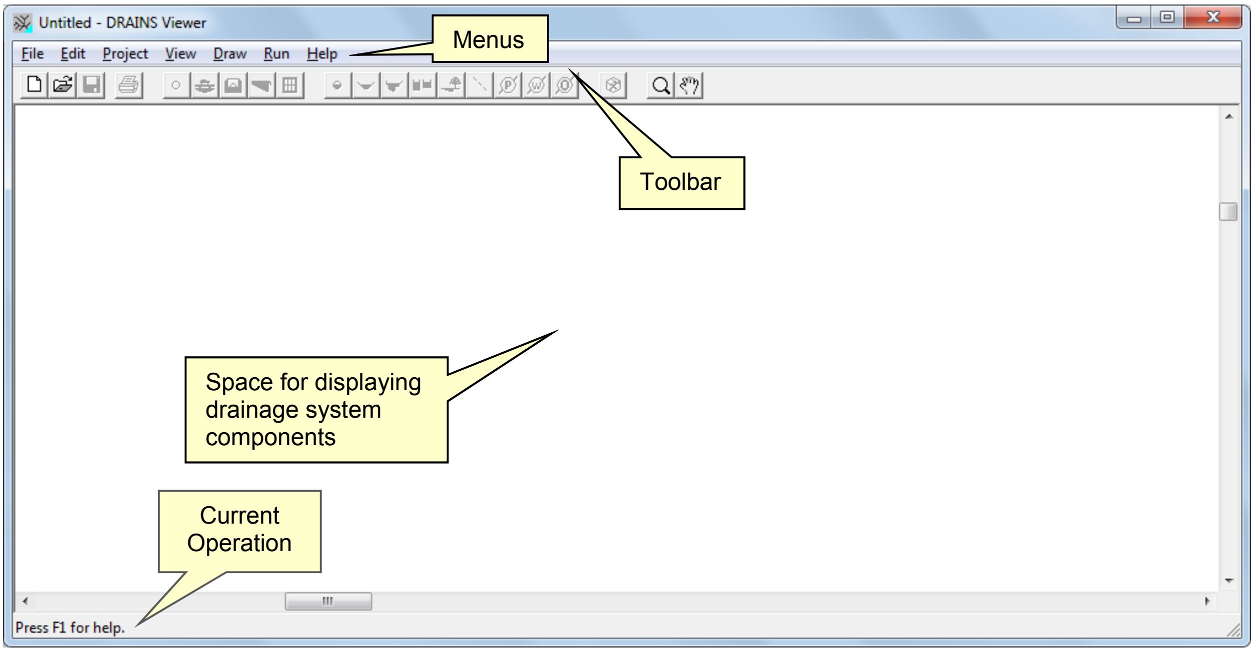


Figure A.1 Main Window of the *DRAINS Viewer*

If you are familiar with *DRAINS* you will find that the *Viewer* operates in the same way except that the model cannot be altered or run.

Initially the *Viewer* will display a blank space. As in *DRAINS*, the operations of the *Viewer* are controlled from menus. Drainage systems are constructed from a set of named components (pits, sub-catchments, pipes, overflow routes, channels, etc. that are joined together as shown in Figure A.2. The information for each component is set out in a property sheet that can be opened by right clicking on the component and selecting **Edit Data** from the pop-up menu.

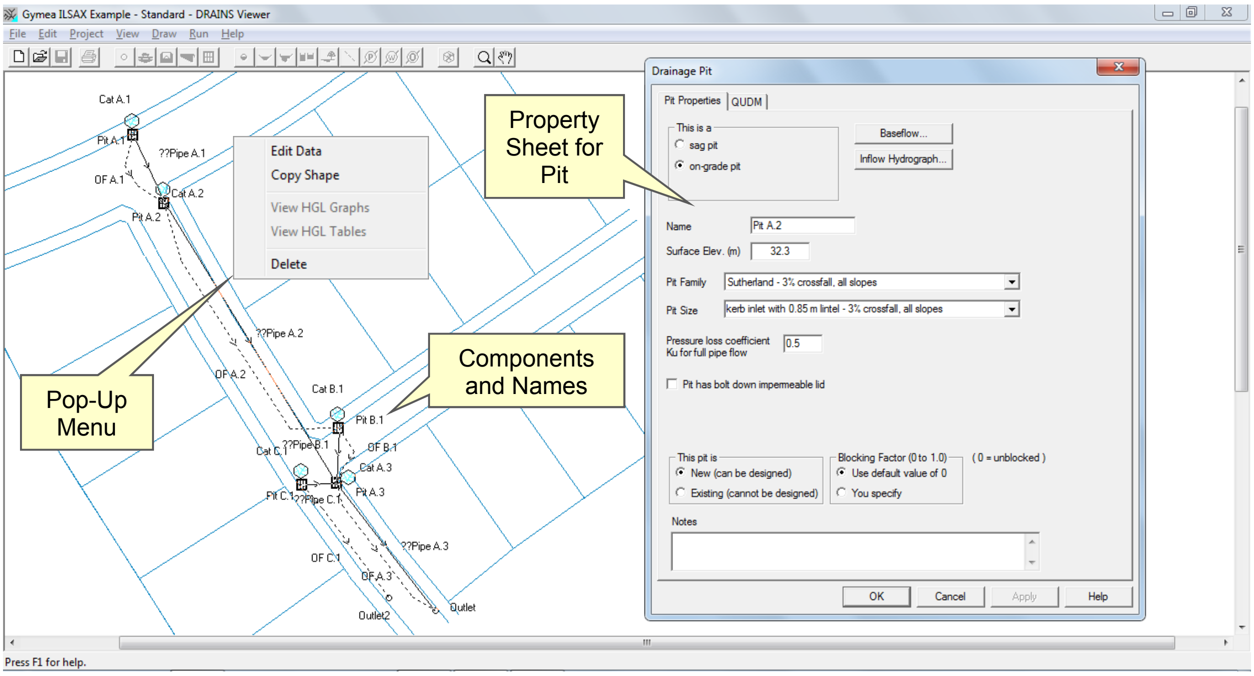


Figure A.2 Gymea Pipe Drainage Example, before a *DRAINS* Run

Running *DRAINS* requires suitable data bases for hydrology, rainfall data, pipes, pits and overflow routes that can be viewed using options in the **Project** menu. After a run, the component names change to colour-coded values of peak flowrates and the levels of hydraulic grade lines (HGLs) at pits and nodes, as shown in Figure A.3. Models can be saved with data and results intact, as a *DRAINS* **`.drn`** file.

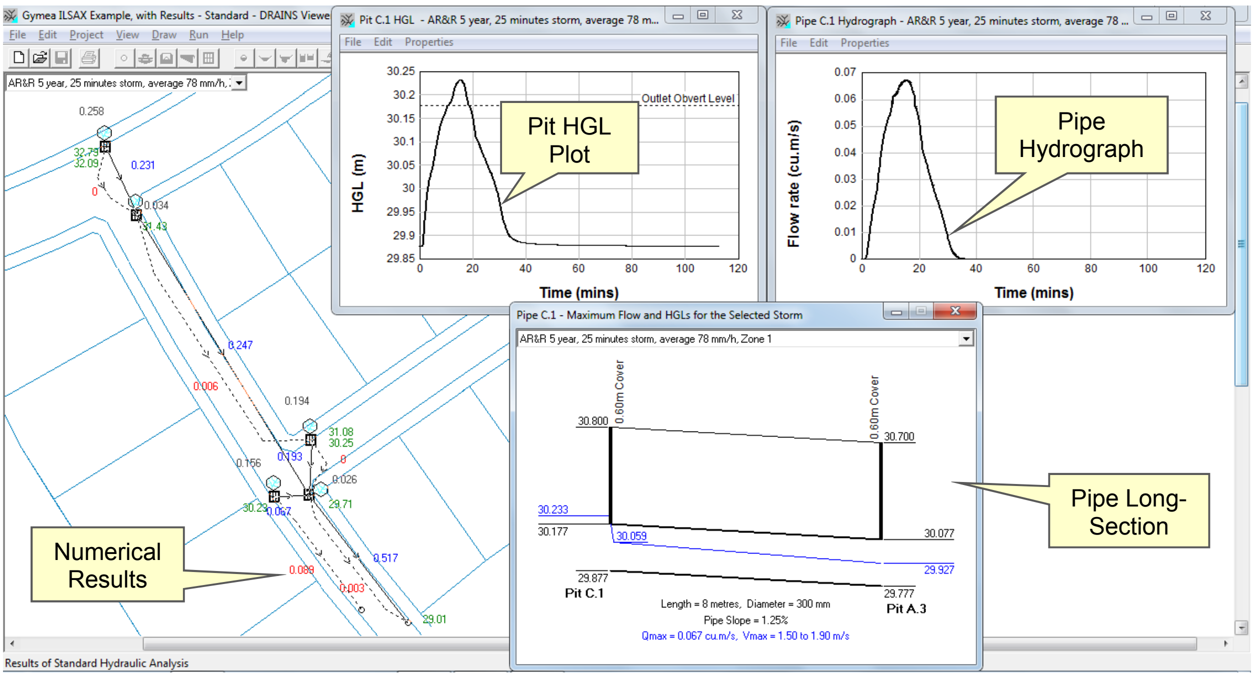
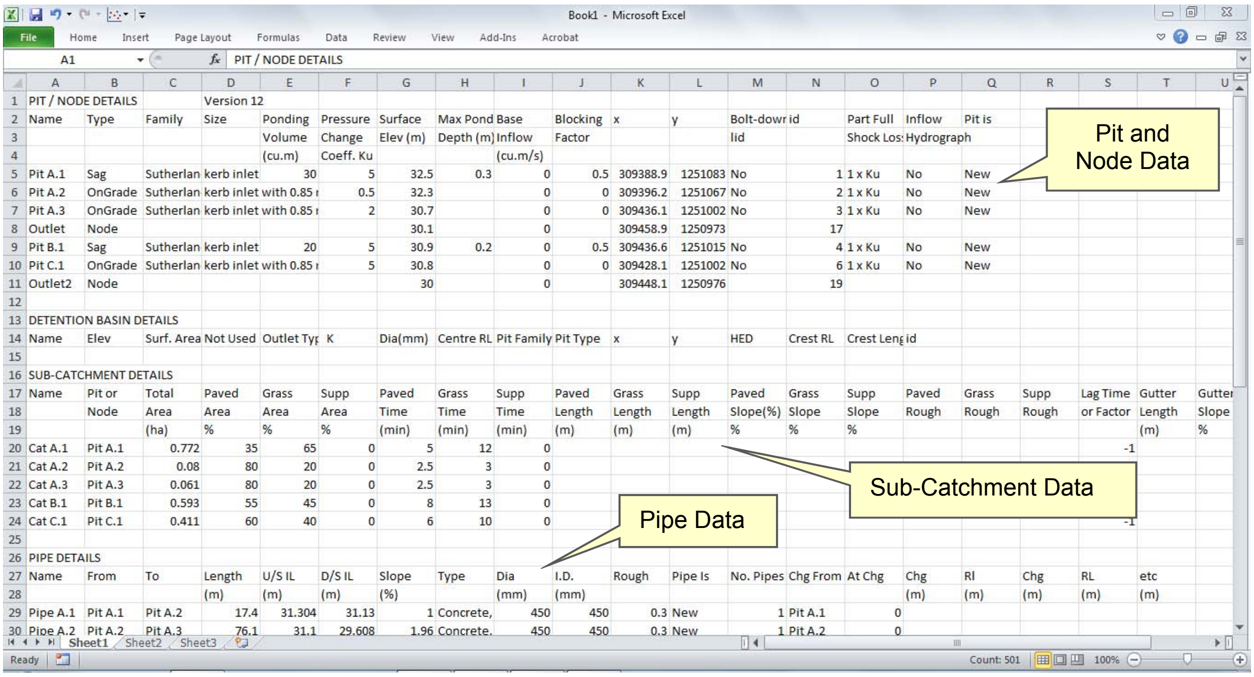


Figure A.3 Results from a Design Run and Standard Hydraulic Analysis of the Gymea Example

To understand this more completely, you can view one of the demonstration examples that are installed with *DRAINS* in **`C:\Program Files\Drains\StandardExamples.`** This file, named **`Gymea ILSAX Example - Standard.drn`**, can be opened using the **Open…** option in the *DRAINS* **File** menu. (Note that if a blank screen appears when a model is loaded, the model can be located using the **Index Sheet** option in the **View** menu.)

The Gymea system, located in suburban Sydney, includes a background showing street and property boundaries imported from a CAD file. Components can be inspected by opening the property sheets for the components, as shown in Figure A.2. If **Property Balloons** is switched on in the **View** menu properties of components can also be seen in balloons that appear as the mouse pointer runs over them.

Data can also be inspected by exporting tables to a spreadsheet via the Windows clipboard, using options in the **Edit** menu. Part of a table is shown in Figure A.4. The facility of viewing long sections of pipelines and transferring them to CAD programs is not available in the Viewer.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	PIT / NODE DETAILS			Version 12																	
2	Name	Type	Family	Size	Ponding	Pressure	Surface	Max Pond	Base	Blocking	x	y	Bolt-dowr	id	Part Full	Inflow	Pit is				
3					Volume	Change	Elev (m)	Depth (m)	Inflow	Factor			lid		Shock Los:	Hydrograph					
4					(cu.m)	Coeff. Ku			(cu.m/s)												
5	Pit A.1	Sag	Sutherlan	kerb inlet	30	5	32.5	0.3	0	0.5	309388.9	1251083	No	1	1 x Ku	No	New				
6	Pit A.2	OnGrade	Sutherlan	kerb inlet	with 0.85 r	0.5	32.3		0	0	309396.2	1251067	No	2	1 x Ku	No	New				
7	Pit A.3	OnGrade	Sutherlan	kerb inlet	with 0.85 r	2	30.7		0	0	309436.1	1251002	No	3	1 x Ku	No	New				
8	Outlet	Node					30.1		0		309458.9	1250973		17							
9	Pit B.1	Sag	Sutherlan	kerb inlet	20	5	30.9	0.2	0	0.5	309436.6	1251015	No	4	1 x Ku	No	New				
10	Pit C.1	OnGrade	Sutherlan	kerb inlet	with 0.85 r	5	30.8		0	0	309428.1	1251002	No	6	1 x Ku	No	New				
11	Outlet2	Node					30		0		309448.1	1250976		19							
12																					
13	DETENTION BASIN DETAILS																				
14	Name	Elev	Surf. Area	Not Used	Outlet Typ	K	Dia(mm)	Centre RL	Pit Family	Pit Type	x	y	HED	Crest RL	Crest Leng	id					
15																					
16	SUB-CATCHMENT DETAILS																				
17	Name	Pit or	Total	Paved	Grass	Supp	Paved	Grass	Supp	Paved	Grass	Supp	Paved	Grass	Supp	Paved	Grass	Supp	Lag Time	Gutter	Gutter
18		Node	Area	Area	Area	Area	Time	Time	Time	Length	Length	Length	Slope(%)	Slope	Slope	Rough	Rough	Rough	or Factor	Length	Slope
19			(ha)	%	%	%	(min)	(min)	(min)	(m)	(m)	(m)	%	%	%					(m)	%
20	Cat A.1	Pit A.1	0.772	35	65	0	5	12	0										-1		
21	Cat A.2	Pit A.2	0.08	80	20	0	2.5	3	0												
22	Cat A.3	Pit A.3	0.061	80	20	0	2.5	3	0												
23	Cat B.1	Pit B.1	0.593	55	45	0	8	13	0												
24	Cat C.1	Pit C.1	0.411	60	40	0	6	10	0										-1		
25																					
26	PIPE DETAILS																				
27	Name	From	To	Length	U/S IL	D/S IL	Slope	Type	Dia	I.D.	Rough	Pipe Is	No. Pipes	Chg From	At Chg	Chg	Rl	Chg	RL	etc	
28				(m)	(m)	(m)	(%)		(mm)	(mm)						(m)	(m)	(m)	(m)	(m)	
29	Pipe A.1	Pit A.1	Pit A.2	17.4	31.304	31.13	1	Concrete,	450	450	0.3	New	1	Pit A.1	0						
30	Pipe A.2	Pit A.2	Pit A.3	76.1	31.1	29.608	1.96	Concrete,	450	450	0.3	New	1	Pit A.2	0						

Figure A.4 Spreadsheet Output of Data for the Gymea Model

Usually, similar names are given to a pit, the sub-catchment draining to it, and the pipe and overflow route carrying water away from it. Overflow routes are an essential part of the model, being used to check that surface flow widths, depths and velocities are not excessive. Even where overflows are required to be zero, a route should be included to demonstrate that this is so.

You will not be able to run this model with the *Viewer*, but you can open another Gymea model named **`Gymea Piped Drainage Model with Results.drn`** from the demonstration examples. This displays the run results shown in Figure A.3. More detailed explanations are provided in the main body of this *DRAINS User Manual* and in the Help system.

A.3 Information Required for Checking

A.3.1 General

This section spells out, in checklists, the basic information required to assess *DRAINS* models for various purposes. The pertinent information is:

- The physical nature of the system, shown in design plans or system diagrams.
- The assumptions made in the design or analysis – these should be reasonable and conform to council requirements, or else be supported by references to manuals or other documents when they differ from council guidelines.
- The extent to which the design meets stated design requirements – systems should convey or store runoff so that flooding of properties and hazards to persons are avoided, at appropriate levels specified by average recurrence intervals (ARIs).

Where a submission accompanies a development application to a municipal council, the design needs to comply with council guidelines that are specified in a number of forms (codes, manuals, development control plans) and are usually available on council or drainage authority websites. It may be reasonable to submit a design that does not meet some requirements, provided that is accompanied by evidence that the submitted design meets the overall purpose.

A.3.2 Property Drainage Systems

For stormwater drainage systems on private properties, *DRAINS* can be used to design gravity and pumped pipework and simulate the behaviour of detention and retention storages. Table A.1 notes the

required and optional information that is normally needed by reviewers. The optional items may be required for assessment if (a) systems are complex, (b) consequences of failure are significant, or (c) precise, documented design is needed.

Table A.1 Typical Requirements for Assessing Property Drainage Systems

Required Items	**Comments**
Plan view of stormwater drainage system, showing locations of downpipes, above- and below-ground pipelines, storages and other features	A concept plan, drawn to scale but not in detail, should be sufficient for most purposes
Plan and section views of on-site detention tanks and surface storages, showing positions and levels of inflow and outflow pipes and discharge control pits	The storage volume provided and sizes of outlet controls such as orifice plates should be noted
Results of on-site detention calculations, including rainwater tanks where these are integrated with OSD storages and allowance for stormwater infiltration where this is provided	The amount of information required depends on the requirement of the council or approving authority. If the method used requires storage routing, *DRAINS* outputs provide the necessary results.
Optional Items	
Pipe long-sections, Table of quantities	Outputs from *DRAINS* may be provided.
Roof gutter and downpipe calculations	Generally only required where consequences of failure are significant.
Pipe design calculations.	Tables of results from *DRAINS* may be provided.

Roof gutters and downpipes are sized to prevent water for storms of a specified ARI overflowing the edges of gutters. The commonly-used design chart from AS/NZS2500.3 is based on hydraulic theory and testing, but methods also incorporate factors of safety such as freeboards (differences between peak water levels and edges of gutters).

ARIs of 20 years are commonly used for eaves gutters on the perimeters of buildings, and 100 years for 'box gutters' that span buildings. Pipe systems should be sized according to the consequences of failure in case of overflows, although some councils specify required ARIs. The usual range is from 5 to 20 year ARI. The ARIs for surface drainage can be smaller than those used for roof design, depending on the relative consequences of failure.

Pipe design methods for property and inter-allotment pipe systems are generally simpler than for street drainage networks, partly because the specification of minimum pipe sizes to prevent blockages leads to overdesign of smaller systems. Typically, requirements are less strict for small developments, or for single dwelling developments compared to multi-unit residential, commercial and industrial developments. In some cases, reviewers may only require a statement or certification that a certain requirement has been met, for example that a roof drainage system has been designed according to AS/NZS2500.3.

OSD is a particularly complex issue, and many methods can be applied, some involving reservoir routing, others employing simple calculations based on factors such as permissible site discharges and site storage requirements specified by the council or drainage authority.
Specified ARIs for on-site detention (OSD) systems vary from council to council, and designers must address stated local regulations. The current trend appears to be to analyse OSD systems for two levels: a low ARI such as 2 years and a high 100 year ARI. The low ARI requirement is likely to have the greatest influence on the storage required. Another trend is to specify double outlets, in series or parallel, which are difficult to analyse. *DRAINS* can accomplish this and allow for high early discharge pits. Stormwater detention systems are discussed further in Section A.5.

A.3.3 Inter-Allotment Drainage Systems

Also known as easement drainage systems, these are pipe and flow path draining through lower properties to a street. As well as (a) a pipe, they involve (b) an overland flow path to carry flows exceeding the pipe capacity, and (c) legal documentation defining the easement, rights of access and prohibitions against obstructions. The usual requirements are:

Table A.2 Typical Requirements for Assessing Inter-Allotment Drainage Systems

Required Items	**Comments**
Plan view of piped drainage system, showing locations of pipes and pits, and extents of flow paths	Optionally, the sub-catchments leading to each pit should be displayed with their areas, and possibly land-uses.
Cross-section of flow path, and sections of any special features such as flow-through fencing	
Optional Items	
Pipe long-sections	Long-sections exported from *DRAINS* can be presented.
Drainage calculations	These can be the relatively simple calculations employed with property drains. *DRAINS* provides these
Table of quantities	Table from *DRAINS* may be presented.

Pipe design ARIs are usually in the range 5 to 20 years, with overflow paths needing to be assessed for 100 year ARI flows.

A.3.4 Street Drainage Systems

Piped drainage systems are required for subdivisions and occasionally for property developments that need to connect to council drainage systems along streets. They may also be required for infrastructure developments such as motorways, airports and port works. The usual documentation required for checking is described in Table A.3. Much of this will be included in subdivision plans, along with drawings of roadworks and other infrastructure.

Table A.3 Typical Requirements for Assessing Street Drainage Systems

Required Items	**Comments**
Plan view of piped stormwater drainage system, showing locations of pipes, pits and other features	On this, or a separate plan, the sub-catchments leading to each pit should be displayed with their areas, and possibly land-uses.
Pipe long-sections	Long-sections exported from *DRAINS* can be used.
Plans and sections of any special pits, junctions or chambers	
Drainage calculations	These are usually set out in tables, following examples in *Australian Rainfall and Runoff*, 1987 and other manuals. *DRAINS* provides comprehensive tabular results. *DRAINS* also produces a plan drawing of the design model.
Optional Items	
Table of quantities, Pit schedule	A table from *DRAINS* may be presented.

Street drainage systems are commonly designed with the major/minor system, for minor ARIs from 5 to 20 year ARI, with 2 year ARI applied in some tropical areas where rainfalls are very high. Most design methods also include a check for fail-safe behaviour in major rainfalls, usually at 100 year ARI. Most calculation software is based on the rational method procedures in *Australian Rainfall and Runoff* 1987 (ARR87) which was developed before use of spreadsheets became common and most calculations were made by hand. The formats of calculations sheets associated with later manuals, such as the *Queensland Urban Drainage Manual* (QUDM), have followed this model.

DRAINS relies on computer computations that go significantly beyond earlier hand calculations, and its tabular outputs do not reproduce simple calculations such as the multiplication of numbers set out in columns. While *DRAINS* data and results are set out in formats similar to the ARR87 calculations, their purpose is to display significant results from the computer calculations, rather than to implement or show any specific calculations.

Design procedures consider surface flows as well as the flows through the pipe system, with the main objectives being:

- preventing flows in street gutters or channels from being too wide (2 to 2.5 m) or deep (kerb height);
- keeping (velocity x depth) products below a limit (typically 0.4 m^2/s) for pedestrian and vehicle safety;
- ensuring that flow levels do not come within a freeboard limit of habitable floor levels in adjoining buildings (generally 0.30 to 0.50 m); and
- within pits, allowing an appropriate freeboard between the pit water level and the surface (generally 0.15 m) to ensure that flows can easily enter pits.

The ways that these can be inspected in *DRAINS* are described in Section 5. Names of pits and pipes should follow a systematic pattern, with each component having a unique name. The names used in *DRAINS* and those displayed on drawings should be consistent.

A.3.5 Trunk Drainage Systems

Runoff from individual pipe systems is collected in open channels located in dedicated flow path or stream corridors. Designs are developed by setting up possible systems in a computer model such as HEC-RAS or *DRAINS*, and then running the model to obtain a satisfactory profile at a design average recurrence interval (ARI) such as 100 years. The arrangement and sizes of channel segments needs to be refined by trial and error to achieve the best result. The required checking documents are set out in Table A.4.

Table A.4 Typical Requirements for Assessing Trunk Drainage Systems

Required Items	Comments
Plan view of trunk drainage system, showing locations of channels, entry points of pipes along the channel and features such as drops and culverts.	Survey set-out information is often included.
Channel long-section profiles and cross-sections.	100 year ARI water surface profiles might be shown
Plans and sections of special features, such as bends, junctions and culverts	
Design report	Detailed calculations are not provided because computer models are used, but results in the report show water surface profiles and indicators such as velocities and freeboards.
Optional Items	
Table of quantities	

General practice for subdivision design is to prepare an initial trunk drainage master plan defining the sizes of channels and detention facilities that need to be provided and the land area required to accommodate these. As detailed design proceeds, these estimates are modified. Design ARIs are 100 year ARI, with probable maximum precipitation (PMP) estimates required where the potential consequences of failure are severe.

A.3.6 Localised Flood Studies

Where developments or re-developments are located along flow paths, or in areas that may be flooded due to water ponding downstream obstructions such as road embankments or existing buildings, a flood study may be required, even for small projects. Councils determine whether such studies are required, relying on reports of past flooding and area-wide modelling that reveals likely riverine and local overland flooding situations.
The extent of the work required can vary considerably with the situation. Where stormwater runoff can flow freely through or beside a development, it may be relatively simple to define a design flowrate and flow path geometry, and to determine flow characteristics such as depths and velocities. However, complex situations may require careful assessment of areas upstream and downstream of the development site, and involve extensive hydraulic modelling.

As shown in Table A.5, study report is usually required, setting out the pre- and post-development situations, the methods applied and the results.

Table A.5 Typical Requirements for Assessing Localised Flood Studies

Required Items	Comments
Flood study report describing the effects of flooding on the proposed development, and measures taken, or needing to be taken, to prevent damage.	The report must be consistent with construction plans of the development

It will be necessary to demonstrate that the new development does not increase the flood hazard affecting future occupants of the development, adjoining and downstream property owners and the public. The results will usually focus upon 100 year ARI floods, but PMP may need to be considered in developments where occupants are vulnerable, such as child care centres or nursing homes.

A.4 Assessing Models and Inputs

A.4.1 General

One of the first issues for the reviewer is to determine whether the model applied is adequate for the task. Guidance can be obtained from *Australian Rainfall and Runoff* (1987) and other manuals, but these are often out of date. Thirty years ago, calculations were generally performed by hand on calculations pads. Now, computer models are now likely to be used in all but a few cases. These can perform such a volume of computations that checking the arithmetic is impossible, so reviewers must consider matters 'external' to the actual calculation process, such as:

- the capabilities of a method or program,
- its suitability for modelling the situation to which it is to be applied, and
- the validity of the parameters used in the model.

DRAINS offers a choice of four types of hydrological model to generate flowrates, and two types of hydraulic model, to calculate flow characteristics. These cover most of the tasks required in urban stormwater practice.

A.4.2 Rainfall Inputs

(a) General

The main input to hydrological models is the design rainfall information provided by the Bureau of Meteorology. This is based on older records, and is being renewed as part of the current revision of *Australian Rainfall and Runoff*. For the present, the design rainfall information from ARR87 is the definitive form of information for general design.

(b) Hydrograph Methods

DRAINS makes rainfall information available through procedures set out in its **Project** menu. The rainfall data is the same for all the hydrological models in *DRAINS* (ILSAX, Extended Rational Method, RORB, RAFTS and WBNM) except the rational method. For the Gymea model introduced in Section 2, which uses the ILSAX model, the **Rainfall Data** option opens the window shown in Figure A.5. This displays a design storm pattern or hyetograph taken from ARR87, which is included in a rainfall data base. Many storms can be included in this base and selected as Minor and Major storms for design calculations.

The intensities used can be viewed and checked against intensity-frequency-duration (I-F-D) charts included in council documents or obtained from the Commonwealth Bureau of Meteorology.

The rainfall patterns selected for a run can be reviewed by looking at the **Select Major Storms** and **Select Minor Storms** options in the **Project** menu, as shown in Figure A.6.

In the Gymea example, only two storms are considered, but designers would normally use 4 to 8 patterns, with durations covering the range where the highest peak flows occur. (Generally, shorter storm durations produce the highest flows in small catchments, but as catchment size increases, the critical duration also increases. Thus, designers might use durations up to 1 or 2 hours for piped drainage systems, and durations from 15 minutes to 3 hours for trunk drainage studies.)

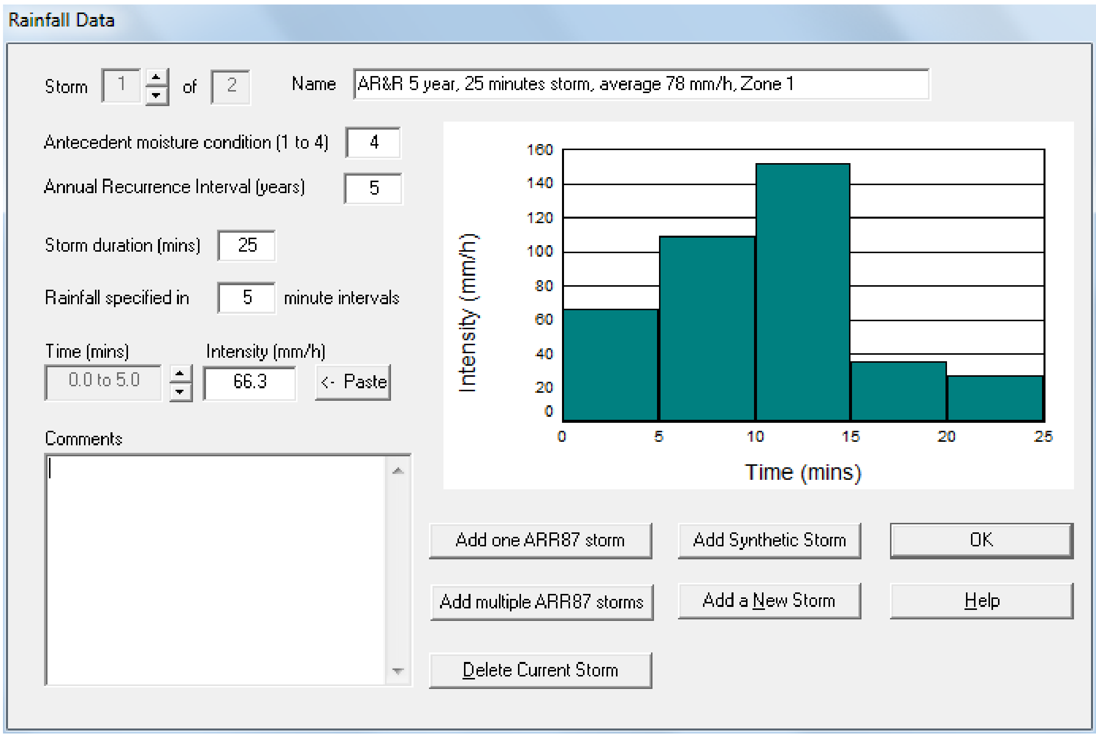


Figure A.5 Rainfall Data Sheet for Hydrograph-Producing Models

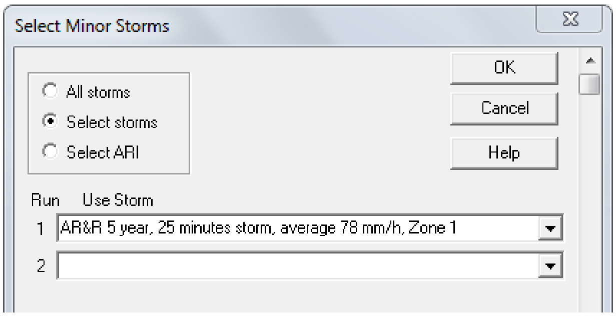


Figure A.6 Window for Selection of Design Storms

(c) Data for the Rational Method

The rational method procedure available in *DRAINS* does not employ rainfall patterns, but instead works from I-F-D information based on the eight rainfall intensities shown in Figure A.7, which appear when the **Rainfall Data** option in the **Project** menu is selected. (You can see this in the Gymea model by changing the hydrological model to a rational method in the drop-down menu in the window that appears when **Hydrological Model** is selected from the **Project** menu.)

(d) Other Rainfall Inputs

Most Australian projects will employ the ARR87 design rainfall data. For specialised studies, actual recorded storms or other required patterns can be imported into *DRAINS* from spreadsheets, or simply typed in. PMP data from the Bureau of Meteorology and special data for the Gold Coast City Council area can be obtained from the *DRAINS* Utility Spreadsheet located on the CD accompanying this Guide. If required, these spreadsheets can be submitted to reviewers.

A.4.3 Hydrology

A.4.3.1 General

All the designs or analyses described in the previous section require the estimation of design flows, otherwise the use of hydraulic calculations is a case of 'garbage in – garbage out'. Designers rely on methods set out in authoritative manuals such as *Australian Rainfall and Runoff* (1987) and the

Queensland Urban Drainage Manual (1992, 2007), but these are far from perfect, due mainly to the dearth of available data for calibrating and testing models.

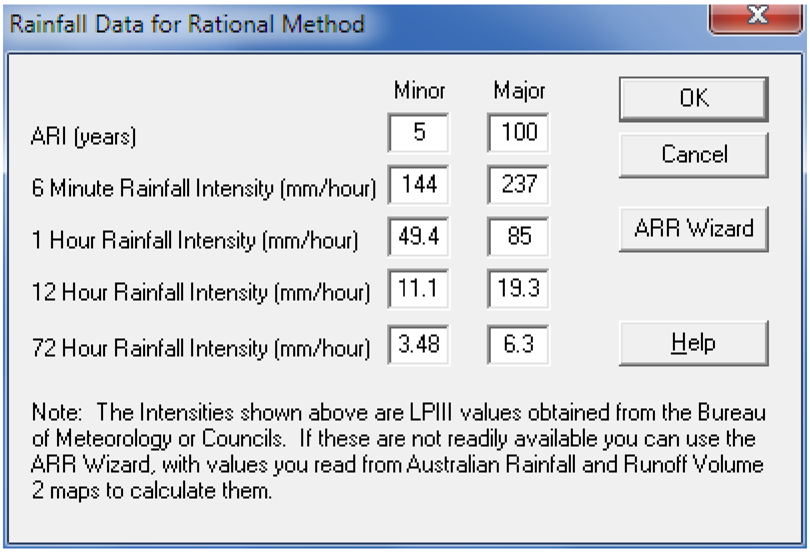


Figure A.7 Rainfall Data Used with the Rational Method in *DRAINS*

The models that are commonly used in urban stormwater practice in Australia are shown in Table A.6. These are only a few of the many models available, but they are the ones that are sanctioned by manuals or have achieved wide use through promotion and recognition of their advantages. Although *DRAINS* offers 'event' models that run with rational method and ILSAX hydrology, and emulate the RORB, RAFTS and WBNM programs, it does not perform continuous modelling of the type carried out by MUSIC.

Table A.6 Urban Hydrological Models Commonly-Used in Australia

Model	Implemented in:	Loss Model	Routing Model
Rational Method	Manual pipe design method in ARR 1887 and software derived from this, manual rural runoff methods (e.g. QUDM); NSW and Victorian probabilistic rational methods (really regional flood frequency procedures)	Both loss and routing effects are incorporated in the selected runoff coefficient C and the time of concentration; generation of hydrographs requires additional assumptions about volumes	
ILSAX Model	*DRAINS* (similar models are applied in xpswmm)	Depression storages and Horton infiltration for pervious areas	Time-area method
RORB	RORB	Initial and continuing losses	Non-linear storage routing
RAFTS	xprafts	Initial and continuing losses	Non-linear storage routing (also contains continuous ARBM model)
WBNM	WBNM	Initial and continuing losses	Non-linear storage routing
Daily Rainfall Runoff Model	MUSIC	Relatively simple continuous daily rainfall model with disaggregation for shorter time steps	Muskingum-Cunge routing between storages

The revision of *Australian Rainfall and Runoff* (see www.arr.org.au) is likely to change the preferred hydrological models, with some of the methods in Table A.6 being superseded. DRAINS will adjust to accommodate any new methods recommended *by Australian Rainfall and Runoff*.

The Extended Rational Method is not included in the above table because it is not yet widely used in Australia. Now available in *DRAINS,* it provides the capability of a hydrograph-producing model using rational method runoff coefficients to practitioners who prefer the rational method.

In many situations, two or more of these models can be validly applied to a catchment, but they are likely to provide different estimates of flowrates. A particular model can also give widely-varying results when applied with different loss and routing parameters. In routine applications, such as the design of a subdivision drainage system, guidance can be obtained from manuals, but for more difficult applications, experience and judgement are needed to select an appropriate model and its parameters.

(b) The ILSAX Model

The ILSAX model will be considered first. To inspect the models in *DRAINS*, choose the **Hydrological Models** option from the **Project** menu to open the window shown Figure A.8. The buttons on the right allow models to be inspected, created or deleted, while the drop-down menu on the left allows alternative models to be selected. The program will apply the selected model when the **OK** button is pressed. If the **Edit Default Model** button is pressed, the window shown in Figure A.9 appears, displaying the model characteristics. This comes from the model in file **`Gymea Piped Drain Model.drn`**, using the hydrological model in the ILSAX program from which *DRAINS* was developed.

The parameters shown are (a) depression storages, which represent depths of water retained in puddles over the whole sub-catchment area, and (b) the soil type, which relates to sets of numbers that control the infiltration rate of water into the soil.

The depression storages apply to the three types of land-use used in ILSAX models:

(a) *paved*, representing the impervious areas directly connected to a drainage system,

(b) *supplementary*, representing impervious areas that are not directly-connected, where runoff must flow over an infiltrating surface before reaching the drainage system, and

(c) *grassed areas*, representing pervious surfaces of various kinds.

Typical values for depression storages are 1 mm for paved and supplementary impervious surfaces, and 5 mm for grassed surfaces. The higher these storages are, the lower the resulting runoff flowrates will be. Values exceeding 2 mm for impervious surfaces and 10 mm for grassed surfaces should be justified.

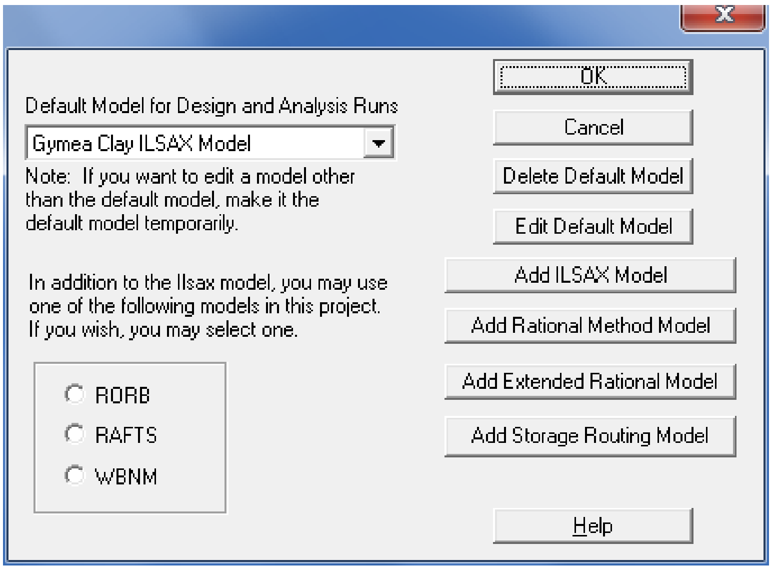


Figure A.8 Hydrological Model Window Specifying an ILSAX Model

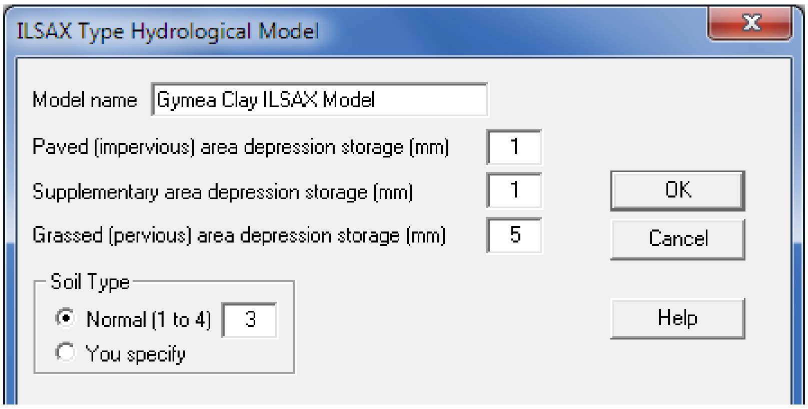


Figure A.9 An ILSAX Model Property Sheet

The soil parameter relates to a system developed by the US Soil Conservation Service. Values from 1 to 4 are commonly selected, based on the following descriptions:

Table A.7 ILSAX Soil Types

Soil Type	Description
1 (or A)	low runoff potential, high infiltration rates (consists of sand and gravel)
2 (or B)	moderate infiltration rates and moderately well-drained
3 (or C)	slow infiltration rates (may have layers that impede downward movement of water)
4 (or D)	high runoff potential, very slow infiltration rates (consists of clays with a permanent high water table and a high swelling potential)

There is a third parameter affecting the infiltration into soils that appears in the rainfall data base. The antecedent moisture condition (AMC) is a number with the same range as the soil type (1 to 4) that indicates the wetness of the soil in the sub-catchment. This is specified for individual storm patterns in the Rainfall Data sheet shown in Figure A.5.

The flowrates calculated by *DRAINS* are sensitive to the AMC selected. The lower the AMC, the higher the infiltration loss into the soil will be, and the lower the runoff. The following table is used to set an AMC based on the expected rainfall in the 5 days prior to a storm
.

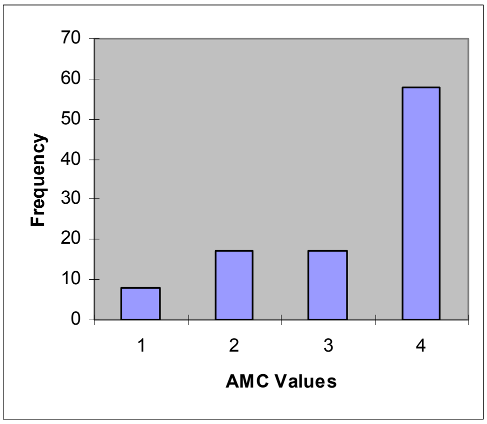
Table A.8 Antecedent Moisture Conditions

Number	Description	Total rainfall in 5 days preceding the storm (mm)
1	Completely dry	0
2	Rather dry	0 to 12.5
3	Rather wet	12.5 to 25
4	Saturated	Over 25

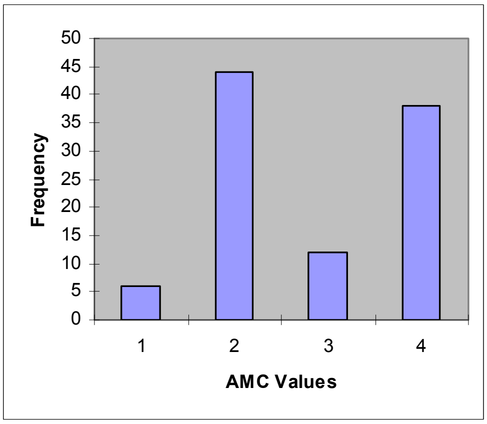
In a design situation, the AMC should reflect the expected conditions prior to a representative future rainfall event. This can be determined by examining records of previous rainfalls near the site. For example, daily rainfalls can be ranked and the 5-day rainfalls prior to the largest rainfall events can be identified. Examples for two locations are shown Figure A.10.

In Section A.4.4, the large variability of model results with AMC is demonstrated. Similar variations can occur with different soil types. Reviewers need to be satisfied that the parameters selected reflect the soil types and wetness occurring at the project site.

An issue that sometimes arises is the application of the ILSAX model to rural catchments. This is uncertain because the ILSAX model has not been calibrated using rural data. The calibrations made to urban data described in Chapter 5 of the *DRAINS User Manual* give confidence that the model will work well where a catchment has a significant impervious portion, say 20% or more, and a man-made drainage system. However, for largely-rural catchments with natural drainage systems, the results are uncertain.



Toowoomba, Queensland (Mean AMC = 3.5)



Perth, WA (Mean AMC = 2.8)

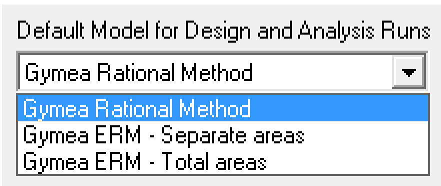
Figure A.10 Histograms of AMCs for Daily Rainfalls 5 Days prior to the 100 Highest Daily Rainfalls on Record

This may be overcome by calibrating the model to peak flow estimates from Chapter 5 of ARR87 (Book 4, Section 1 in the 1998 version) such as the NSW Probabilistic Rational Method. The main *DRAINS* parameter that can be changed to alter flows is the time of concentration for pervious areas, but other parameters such as the AMC and depression storages may also be changed. It will be necessary to analyse a number of storm durations to obtain a worst-case flowrate.

Where *DRAINS* is applied in rural conditions, the procedure should be outlined and the assumptions regarding parameters and results made clear in reports submitted to reviewers.

(c) The Rational Method and the Extended Rational Method

DRAINS also offers a procedure that carries out rational method calculations. This can be viewed in the Gymea model by choosing the **Hydrological Model…** option in the **File** menu, and selecting the Gymea Rational Method model shown below:



This can then be viewed by clicking the **Edit Default Model** button. The model that appears is likely to be an ARR87 model using the procedures from *Australian Rainfall and Runoff*, 1987, as shown in Figure A.11.

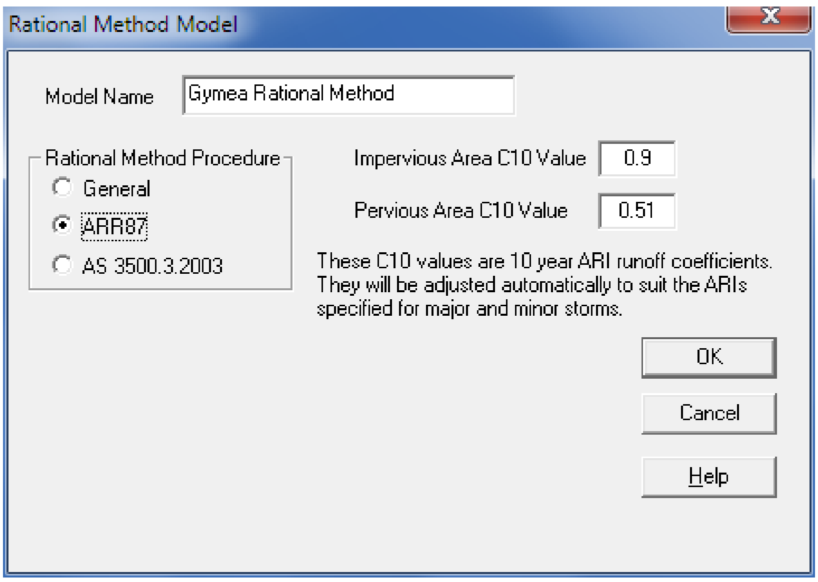
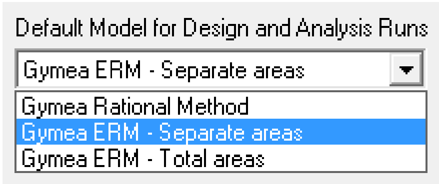


Figure A.11 Property Sheet for a Rational Method Model

This model uses two runoff coefficients, 0.9 for impervious areas and 0.51 for pervious areas. The latter is based on the 10 year ARI, 1 hour duration design rainfall intensity for Gymea, as described in Section 14.5.5 of ARR87 (Section 1.5.5. of Book 8 of the 1998 version). The rational method averages these runoff coefficients according the specified impervious and pervious areas using a much simpler procedure than that applied in the ILSAX model.

The run results are similar to those from the ILSAX model, except that peak flowrates are produced but no hydrographs of flow, so the results cannot be used to model detention storages, as ILSAX and other hydrograph-producing models can.

To meet the needs of users wanting to apply the rational method to detention basin calculations, an extended rational method (ERM) has been provided in *DRAINS*. This can be selected from the **Hydrological Models…** property sheet as shown below:



The parameters required are shown in Figure A.12. The ERM determines a runoff volume based on the runoff coefficients supplied and then uses the same time-area routing procedure as the ILSAX model to produce hydrographs. Consequently hydrographs can be produced from ARR87 rainfall patterns, but because of the different infiltration assumptions, these will differ from ILSAX hydrographs produced from the same rainfall patterns.

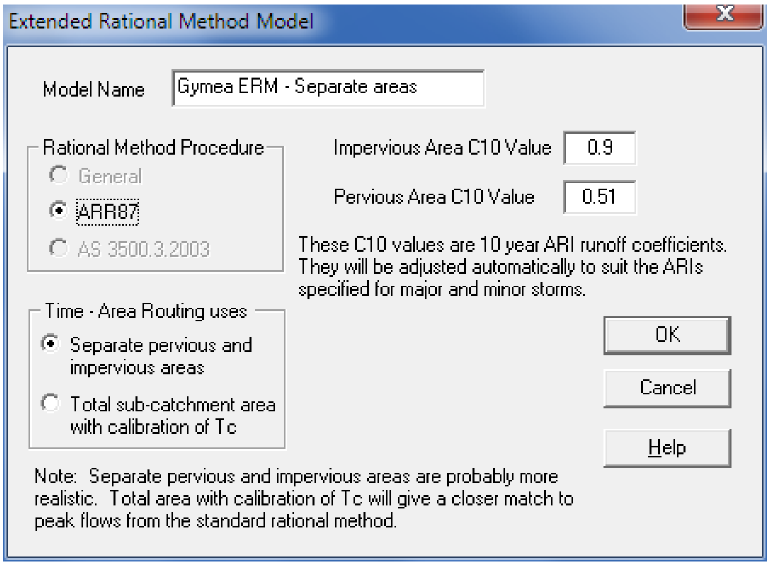


Figure A.12 Property Sheet for an Extended Rational Method Model

The ERM peak flowrates will also differ from the rational method flowrates unless the following actions are taken:

(a) the Total sub-catchment area option is selected in the box shown at the bottom-left of Figure A.12; and

(b) a synthetic rainfall pattern based on the I-F-D relationship for the site is applied, instead of the ARR87 storm patterns, which are not used by the rational method.

These issues are described in detail in the *DRAINS User Manual* and Help system.

The rational method is suited to basic pipe system design without storage effects, but is a poor analysis model. Assumptions about timing of peak flowrates must be made to estimate what happens in larger flood events and this becomes a more complicated task than running a hydrograph-producing model. The ERM provides a hydrograph model based on rational method principles. This is unique to *DRAINS* and is not covered in manuals, but the principles used are similar to methods commonly applied in the UK and US.

A.4.4 Comparison of Hydrological Methods for Piped Drainage Systems

This section provides comparative information on the three models provided by   for use with piped drainage systems. An example based on the Gymea model is shown in Figure A.13 and the sub-catchment characteristics relevant to the ILSAX and rational method models are shown in Table A.9. The focus is on the runoff produced by the sub-catchments and flows in pipes are not considered in this assessment. An additional sub-catchment has been added at the outlet to model a sub-catchment that is mainly pervious.

Table A.10 sets out the results of a series of runs made with the modified Gymea model. . Four ILSAX models apply a typical Soil Type of 3 and AMC values of 1, 2, 3 and 4. The rational method uses a 10 year ARI pervious area runoff coefficient of C_{10} = 0.51, based on a 10 year ARI, 1 hour intensity of 56 mm/h to develop 5 and 100 year ARI coefficients of C_5 = 0.48 and C_{100} = 0.61. The extended rational method (ERM) uses the same coefficients, but is applied in three ways, with ARR87 and synthetic storms being used, and impervious and pervious runoff being calculated separately or on a total basis. Times of concentration are consistent for all models.

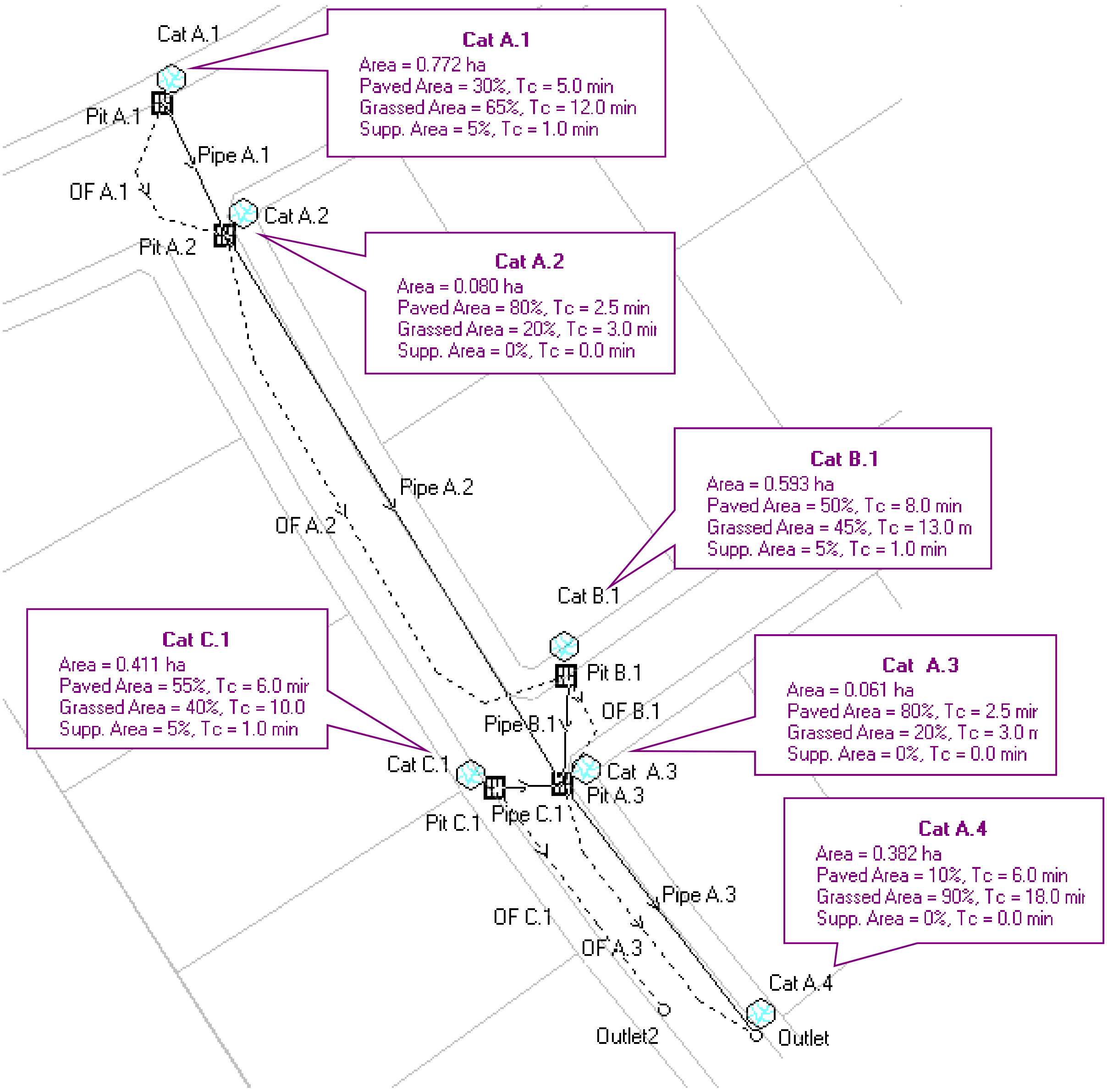


Figure A.13 Gymea Model used for Comparisons

Peak flowrates for 5 and 100 year ARI are shown for each sub-catchment. Those from the ILSAX models and the ERM with ARR87 storms are the highest values out of twelve storm patterns with durations from 5 minutes to 4.5 hours.

Table A.9 Characteristics of Comparative Gymea Model Sub-Catchments

Sub-Catchment	**Area** (ha)	**Hydrological Model**					
		ILSAX		**Rational Method and ERM**			
		Paved, Supplementary & Grassed %	Paved, Supplementary & Grassed t_c (minutes)	Impervious & Pervious %	Impervious & Pervious. t_c (minutes)	Imperv. C_{10}	Perv. C_{10}
Cat A.1	0.772	30, 5, 65	5, 1, 12	35, 65	5, 12	0.9	0.51
Cat A.2	0.08	80, 0, 20	2.5, 0, 3	80, 20	2.5, 3	0.9	0.51
Cat A.3	0.061	80, 0, 20	2.5, 0, 3	80, 20	2.5, 3	0.9	0.51
Cat A.4	0.382	10, 0, 90	6, 0, 18	10, 90	6, 18	0.9	0.51
Cat B.1	0.593	50, 5, 45	8, 1, 13	55, 45	8, 13	0.9	0.51
Cat C.1	0.411	55, 5, 40	6, 1, 10	60, 40	6, 10	0.9	0.51

Table A.10 Comparison of Flowrates and Volumes Generated by Gymea, New South Wales Pipe System Models

Sub-Catchment	**Hydrological Model**							
	ILSAX with Soil Type of 3 and AMC of				**Rational Method**	**ERM*** with:		
	1	2	3	4		Separate ARR87 Storms	Separate areas, Synthetic	Total areas, Synthetic
5 Year ARI Flowrates (m^3/s)								
Cat A.1	0.114	0.179	0.220	0.255	0.145	0.179	0.169	0.145
Cat A.2	0.027	0.031	0.033	0.034	0.027	0.027	0.027	0.027
Cat A.3	0.021	0.024	0.025	0.026	0.020	0.020	0.020	0.020
Cat A.4	0.019	0.045	0.081	0.098	0.051	0.056	0.053	0.051
Cat B.1	0.122	0.145	0.174	0.192	0.128	0.147	0.138	0.129
Cat C.1	0.100	0.121	0.142	0.155	0.103	0.114	0.110	0.103
100 Year ARI Flowrates (m^3/s)								
Cat A.1	0.301	0.340	0.393	0.424	0.294	0.336	0.337	0.294
Cat A.2	0.050	0.053	0.054	0.055	0.052	0.051	0.052	0.052
Cat A.3	0.038	0.040	0.041	0.042	0.039	0.039	0.039	0.039
Cat A.4	0.087	0.124	0.150	0.164	0.106	0.113	0.109	0.106
Cat B.1	0.248	0.268	0.297	0.316	0.254	0.274	0.272	0.253
Cat C.1	0.196	0.217	0.232	0.241	0.202	0.209	0.215	0.201
5 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
Design Storm								
5 minute	36	38	52	69	n/a	65		
25 minute	39	51	71	84		65		
4.5 hour	46	59	72	80		65		
Synthetic							65	65
100 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
5 minute	44	54	70	81	n/a	78		
25 minute	56	69	82	91		78		
4.5 hour	68	76	83	88		78		
Synthetic							78	78

* The ERM dies not run with the total area assumption and ARR87 storms

Relative results vary with the proportions of impervious and pervious areas, but the rational method and ERM generally specify lower flowrates than the ILSAX models, specially where an AMC or 3 or 4 is used, which will be the usual situation at Gymea.

The reasons for the rational method providing lower flowrates than ILSAX are:

- ILSAX uses ARR87 patterns such as that shown in Figure A.5, which contain higher peak intensities than the rational method, which assumes that rainfall occurs as a rectangular block.
- The ILSAX hydrological model gives different runoff volumes to the rational method and applies different routing procedures. It only applies a depression storage loss of 1 mm for impervious areas while the rational method and ERM apply C_5 = 0.86 and C_{100} = 1.0.

The three alternative ERM combinations demonstrate how this model produces different peak flows depending on the assumptions and rainfall inputs applied. The last of the three variations provides peak flowrates that are the same as the rational method estimates.

Table A.10 also displays the volumes of hydrographs generated for selected storm patterns. These are expressed as a percentage of the total rainfall in these patterns. The ILSAX models show a spread of volumes depending on AMCs and storm durations, while the ERM results show consistent volumes of 65% for 5 year ARI and 78% for 100 year ARI. These percentages are the weighted average C values obtained from the impervious and pervious coefficients. The ERM assumes that the volumetric coefficient (ratio of total runoff to total rainfall) is the same as the runoff coefficient used to define peak flowrates.

A designer at Gymea using a (Soil Type, AMC) combination of (3, 3) or (3, 4) would generally generate greater volumes than from the ERM. If the results were applied to a detention basin design, a larger storage would be required when the ILSAX mode is used.

Similar variations in ILSAX model results to those caused by AMC occur when Soil Types are changed, although the extent of variations is not as great.

To check whether these results apply in other parts of Australia, the analysis has been applied using rainfall and parameter values applying at a location with higher rainfalls, the suburb of Manly in Brisbane, and a site with lower rainfall – Port Adelaide, South Australia. Results from models adapted from the Gymea model are shown in Table A.11 and Table A.12.

At Manly, the 10 year ARI, 1 hour rainfall intensity of 68 mm/h leads to pervious area runoff coefficients of C_{10} = 0.67, C_5 = 0.64 and C_{100} = 0.80. An AMC of 3 is used for comparisons. The impervious area coefficients are the same as at Gymea, and the comparative results are similar to those at Gymea, with the ILSAX models giving higher peak flows and volumes.

At Port Adelaide, the 10 year ARI, 1 hour rainfall intensity of 24.5 mm/h defines pervious area runoff coefficients of C_{10} = 0.10, C_5 = 0.095 and C_{100} = 0.12. The Soil Type is assumed to be 2, reflecting sandy soils, and combined with the lower rainfall intensities, runoff can be assumed to be much lower than at Gymea and Manly. The ILSAX estimates in Table A.12 are generally below the rational method peaks and volumes. Even if the AMC is set at 3, the rational method estimates are still slightly higher, although the differences in flows and volumes are small.

These comparisons are provided as information for designers and reviewers. It is beyond the scope of this Guide to argue the merits of the individual models.

Other Hydrological Models in DRAINS

DRAINS can also apply runoff routing or storage routing models emulating the RORB, RAFTS and WBNM programs described in Chapter 5 of this manual. These can be viewed using the **Hydrological Models…**option in the **Project** menu, which appears as shown in Figure A.14.

Runoff routing model can be run together with an ILSAX model in *DRAINS*. This is convenient where the tailwater affecting a small urban drainage system is created by flows from a larger urban rural catchment. A number of storm events can be modelled without having to transfer data and results between models.

Further information on the *DRAINS* implementation of these models is provided in the *DRAINS* Manual and the Help system. The models and their results can be inspected using the *Viewer* in the same way as the ILSAX and rational method models.

Table A.11 Comparison of Flowrates and Volumes Generated by
Manly, Queensland Pipe System Models

Sub-Catchment	Hydrological Model							
	ILSAX with Soil Type of 3 and AMC of				**Rational Method**	**ERM*** with:		
	1	2	3	4		Separate ARR87 Storms	Separate areas, Synthetic	Total areas, Synthetic
5 Year ARI Flowrates (m^3/s)								
Cat A.1	0.179	0.231	0.292	0.329	0.209	0.254	0.237	0.209
Cat A.2	0.038	0.040	0.041	0.042	0.034	0.034	0.034	0.034
Cat A.3	0.029	0.030	0.031	0.032	0.026	0.026	0.026	0.026
Cat A.4	0.038	0.064	0.098	0.120	0.08	0.085	0.081	0.08
Cat B.1	0.170	0.197	0.226	0.245	0.171	0.199	0.185	0.171
Cat C.1	0.139	0.160	0.184	0.193	0.136	0.153	0.146	0.136
100 Year ARI Flowrates (m^3/s)								
Cat A.1	0.367	0.429	0.483	0.512	0.416	0.465	0.466	0.416
Cat A.2	0.063	0.065	0.067	0.068	0.066	0.066	0.066	0.066
Cat A.3	0.048	0.050	0.051	0.052	0.05	0.050	0.050	0.050
Cat A.4	0.111	0.149	0.181	0.196	0.163	0.167	0.165	0.163
Cat B.1	0.305	0.336	0.366	0.385	0.332	0.361	0.362	0.330
Cat C.1	0.247	0.267	0.281	0.290	0.262	0.274	0.283	0.261
5 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
Design Storm								
5 minute	38	44	61	75	n/a	73		
25 minute	46	60	76	87		73		
4.5 hour	50	63	75	82		73		
Synthetic							73	73
100 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
5 minute	50	62	75	84	n/a	89		
25 minute	63	74	85	92		89		
4.5 hour	71	78	85	89		89		
Synthetic							89	89

These three established models were made available in *DRAINS* to model rural or largely-rural catchments. The time-area procedure used by ILSAX has not been calibrated to rural catchment data, while the other three have been extensively tested and used in rural environments, and are supported in *Australian Rainfall and Runoff*, 1987.

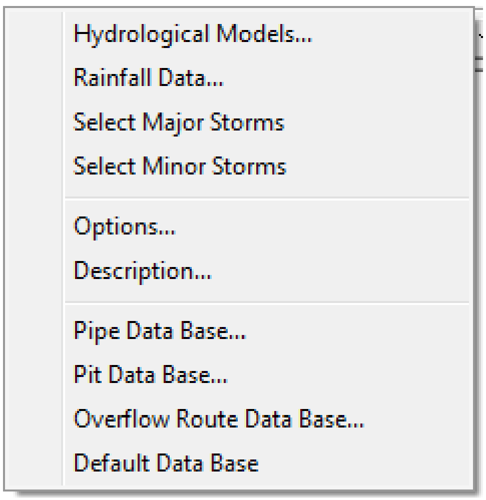
The emulations of the models will give similar answers to the original RORB, RAFTS and WBNM models, but there may be differences in flowrates due to different computational procedures and the many different features in the operation of these models. For example, the RAFTS model in *DRAINS* is simpler and has less features that the xprafts program provided by xpsoftware. Designers and reviewers will need to ensure that the correct parameters for a location are applied. These may come from published relationships such as those in Chapter 9 of ARR87 (Book 5, Section 3 of the 1998 version), or by calibrating the storage routing model to rural model peak flow estimates from Chapter 5 of ARR87 (Book 4, Section 1 in the 1998 version).

Table A.12 Comparison of Flowrates and Volumes Generated by Port Adelaide Pipe System Models

Sub-Catchment	**Hydrological Model**							
	ILSAX with Soil Type of 2 and AMC of				**Rational Method**	**ERM*** with:		
	1	2	3	4		Separate ARR87 Storms	Separate areas, Synthetic	Total areas, Synthetic
5 Year ARI Flowrates (m^3/s)								
Cat A.1	0.046	0.046	0.046	0.056	0.054	0.054	0.056	0.054
Cat A.2	0.014	0.014	0.014	0.014	0.012	0.012	0.012	0.012
Cat A.3	0.011	0.011	0.011	0.011	0.009	0.009	0.009	0.009
Cat A.4	0.007	0.007	0.009	0.009	0.009	0.01	0.01	0.009
Cat B.1	0.051	0.051	0.051	0.058	0.052	0.052	0.053	0.052
Cat C.1	0.042	0.042	0.042	0.047	0.044	0.041	0.045	0.044
100 Year ARI Flowrates (m^3/s)								
Cat A.1	0.112	0.122	0.122	0.208	0.152	0.153	0.159	0.152
Cat A.2	0.033	0.033	0.033	0.040	0.034	0.034	0.034	0.034
Cat A.3	0.025	0.026	0.026	0.031	0.026	0.026	0.026	0.026
Cat A.4	0.015	0.017	0.017	0.087	0.025	0.025	0.029	0.025
Cat B.1	0.112	0.114	0.114	0.169	0.145	0.133	0.147	0.145
Cat C.1	0.092	0.097	0.097	0.134	0.123	0.111	0.125	0.123
5 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
Design Storm								
5 minute	33	33	33	33	n/a	42		
25 minute	37	37	37	40		42		
4.5 hour	38	38	38	38		42		
Synthetic							42	42
100 Year ARI Runoff Volumes from the Whole Catchment (% of Rainfall)								
5 minute	37	37	37	61	n/a	50		
25 minute	38	38	38	71		50		
4.5 hour	39	39	39	56		50		
Synthetic							50	50

A.4.5 Pipe, Pit and Overflow Route Data Bases

When *DRAINS* runs it refers to data bases describing the hydrological model, rainfall data and details of the pipe, pit and overflow routes specified in the property sheets for various components. This information can be seen in the *Viewer* by (a) opening the property sheets for components, (b) using the property balloons (see Figure A.16), or (c) transferring data to a spreadsheet. The transfer options are shown to the right.



The data bases can also be viewed using options from the **Project** menu. Details are covered in the Manual and Help system.

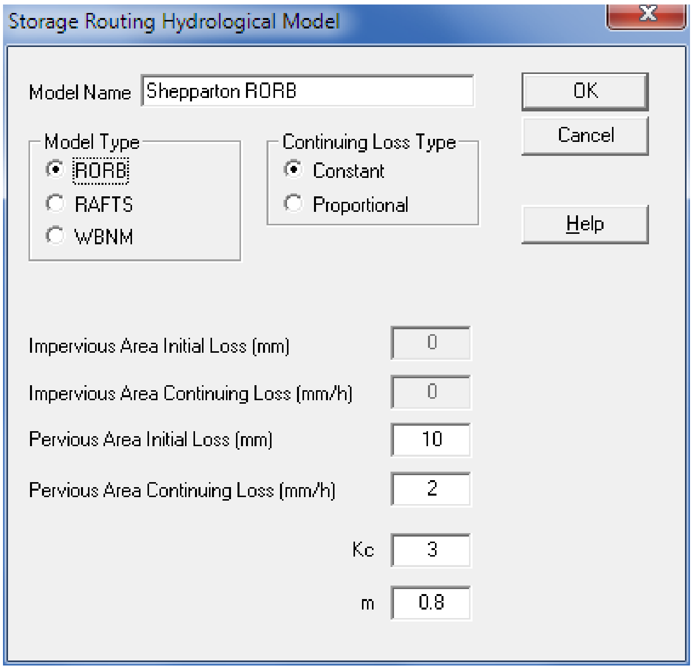


Figure A.14 Model Property Sheet for a RORB Model

The data bases selected should obviously reflect the conditions at the site. Users can create their own pipes, pits or overflow routes by adding information to the data bases. In analysing existing systems, this may be necessary because a pit may be an obsolete type for which no inlet capacity information is available. A Generic Spreadsheet for Pit Inlet Capacities, provided on the accompanying CD, can be used to establish relationships for these pits. Where inlet capacity is an important consideration, details should be provided with any design or analysis documentation.

A.4.6 Hydraulics

Designers apply hydraulic methods to determine flow characteristics corresponding to hydrological flow estimates. These characteristics – water levels, depths, widths, velocities and products of depths and velocities, are used to decide whether the flow is being conveyed safely along a pipe or channel.

There has been rapid development of hydraulic models recently, particularly 2-dimensional models of surface flows. Table A.13 and Table A.14 provide a classification of models, with examples of the software used in Australia. The first two types in Table A.13 are procedures that can be implemented with a calculator, while the others are packages that organise large amounts of data describing the geometry and characteristics of pipes, channels and flow paths.

Table A.13 Pipe System Hydraulic Models

Model	Implemented in:
Estimation of velocities and flow capacities for pipe-full 'but not under pressure' conditions	Manual calculations using Manning's equation or a similar relationship
Normal depth calculations estimating flow depths, velocities and other characteristics for a given flowrate (involving simple iterative procedures)	Manual or spreadsheet calculations, or simple overflow route calculations in programs such as *DRAINS*
Projection of hydraulic grade lines through pipe systems, allowing for full- and part-full flow, pipe friction and pit pressure losses	*DRAINS* basic hydraulics model (now obsolete)
1-D unsteady water surface profile calculations through pipes using Priessmann slot or similar methods to model full-pipe flows	*DRAINS*, SWMM, xpswmm, Mouse,

The basic hydraulics procedure was the first model implemented in DRAINS. It is now obsolete, and only available in models developed with pre-2011 versions of DRAINS. The current standard and premium hydraulic models both apply unsteady flow hydraulic calculations in pipes and channels. They differ in the hydraulic calculations for overflow routes. The standard model assumes uniform flows, providing information based on normal depth calculations for the peak calculated flows at a nominated point along

the overflow route. The premium model calculates a full water surface profile along overflow routes, allowing for tailwater levels. Because it allows for stored surface water at pits and in along flow paths, it usually specifies lower flowrates and water levels than the standard model. Thus, the standard model can be considered to give results that are conservatively high.

Table A.14 Hydraulic Models applicable to Open Channels and Overflow Routes

Model	Implemented in:
Estimation of flow capacities and velocities for a given flow depth (channel-full levels)	Manual calculations using Manning's equation or a similar relationship
Normal depth calculations estimating flow depths, velocities and other characteristics for a given flowrate (involving simple iterative procedures)	Manual or spreadsheet calculations, or simple models in programs such as HEC-RAS or *DRAINS* (overflow routes only in basic hydraulic model)
1-dimensional (1D) steady water surface profile calculations - sub-critical, supercritical or mixed (both)	HEC-RAS, DRAINS basic hydraulic model (now obsolete)
1-D quasi-unsteady water surface profile (a series of steady state calculations)	*DRAINS* basic hydraulics model (obsolete)
1-D unsteady water surface profile calculations	RUBICON, MIKE11, xpswmm, HEC-RAS, *DRAINS*
Quasi-2-dimensional surface flow models created by linking 1-D unsteady flows in a network with suitable overflow controls	CELLS (obsolete), MIKE11, xpswmm, *DRAINS*
2-dimensional (2-D) surface flow models	RMA-2 (using finite elements), MIKE 21, Sobek and TUFLOW (finite differences, finite volume), Info works 2D (boundary elements), ANUGA (finite volume)
Integrated 1-D - 2-D surface flow models	MIKE Flood (MIKE11 + MIKE21), Sobek, TUFLOW, xp2d (xpswmm + TUFLOW)
Integrated 1-D - 2-D surface flow models combined with unsteady pipe flow models	MIKE Flood + MOUSE, Sobek, TUFLOW, xp2d (xpswmm + TUFLOW)

Reviewers can tell which hydraulic model has been used to produce a set of results from the status bar at bottom left of screen.

Information on the working of the models and their data requirements are given in the *DRAINS User Manual* and Help system. Reviewers will mainly be concerned with the results, particularly with the water levels estimated. Methods of checking these are described in the following section.

In pipe system calculations, peak flowrates are assumed to occur simultaneously in the rational method, but in hydrograph models such as the ERM and ILSAX, allowance is mode for the peaks occurring at different times due to varying times of concentration. The calculation and checking procedure set out in ARR87 (Tables 14.14 and 14.16, or Tables 1.14 and 1.16 in the 1998 version).does not properly describe the processes in hydrograph models which usually specify lower HGLs.

An important issue in modelling, beyond the scope of this Guide, is the selection of a model that is adequate for the task. Judgements on this require theoretical knowledge of hydraulics as well as experience with models. The *DRAINS* pipe models have been tested and can be applied by relatively inexperienced designers. Open channel calculations may require knowledgeable interpretation and any modelling of large or critical systems should be done by experienced engineers.

DRAINS models allow flows to be reversed, for example, when high water levels or pressures in a pipeline force water back through side branches. This may not be obvious from the initial display of peak flows, because DRAINS only displays the peak positive pipe flowrate, so it will be necessary to explore results and property sheets. Both *DRAINS* hydraulic models can sometimes display instabilities (rapidly fluctuating water surfaces) or spikes (sudden rises and falls in water level and flowrates). These are typically caused by overshooting of interpolation and extrapolation calculations, and can usually be ignored after checking the model. If instabilities are present in any models submitted to a reviewer, explanations or interpretations should also be provided, indicating that these will not invalidate the results.

A.5 Checking Model Components, Flowrates and Water Levels

A.5.1 Viewing Pipe System Components

Components can be inspected by opening property sheets (Figure A.15), property balloons (Figure A.16) or transferring data to a spreadsheet via the Windows Clipboard using options in the Edit menu (Figure A.17). The spreadsheet data output is the only easy way of detecting baseflows and user-provided hydrographs.

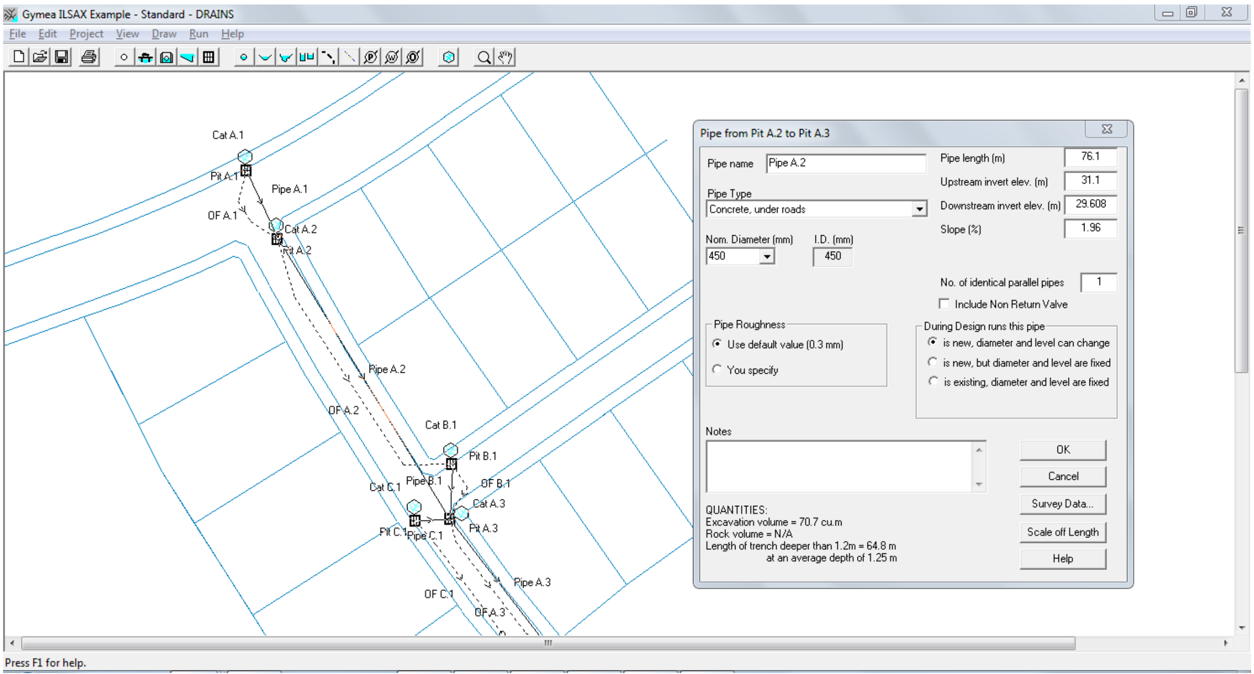


Figure A.15 Pipe Property Sheet

Pipes and pits can be inspected using long section window called from the pop-up menu for a pipe (Figure A.18) and from the multi-pipe long sections that can be created in the **Export** option in the **File** menu by specifying a route between pits (Figure A.19).

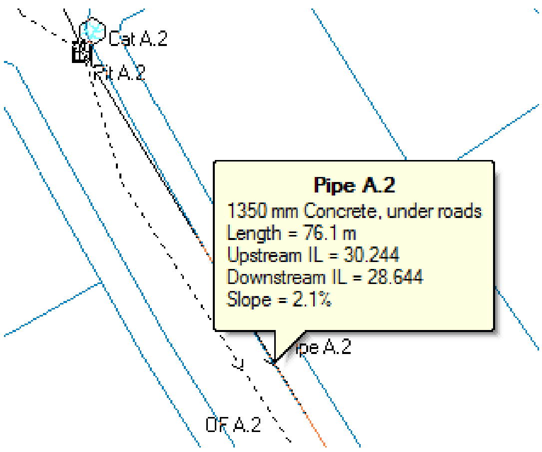


Figure A.16 Balloon Showing Pipe Data

25																
26	PIPE DETAILS															
27	Name	From	To	Length	U/S IL	D/S IL	Slope	Type	Dia	I.D.	Rough	Pipe Is	No. Pipes	Chg From	At Chg	Chg
28				(m)	(m)	(m)	(%)		(mm)	(mm)						(m)
29	Pipe A.1	Pit A.1	Pit A.2	17.4	30.614	30.414	1.15	Concrete,	1200	1200	0.013	New	1	Pit A.1	0	
30	Pipe A.2	Pit A.2	Pit A.3	76.1	30.244	28.644	2.1	Concrete,	1350	1370	0.013	New	1	Pit A.2	0	
31	Pipe A.3	Pit A.3	Outlet	37.7	28.184	27.434	1.99	Concrete,	1800	1800	0.013	New	1	Pit A.3	0	
32	Pipe B.1	Pit B.1	Pit A.3	12.8	29.145	28.945	1.56	Concrete,	1050	1070	0.013	New	1	Pit B.1	0	
33	Pipe C.1	Pit C.1	Pit A.3	8	29.555	29.38	2.19	Concrete,	600	600	0.013	New	1	Pit C.1	0	
34																

Figure A.17 Part of Spreadsheet Output

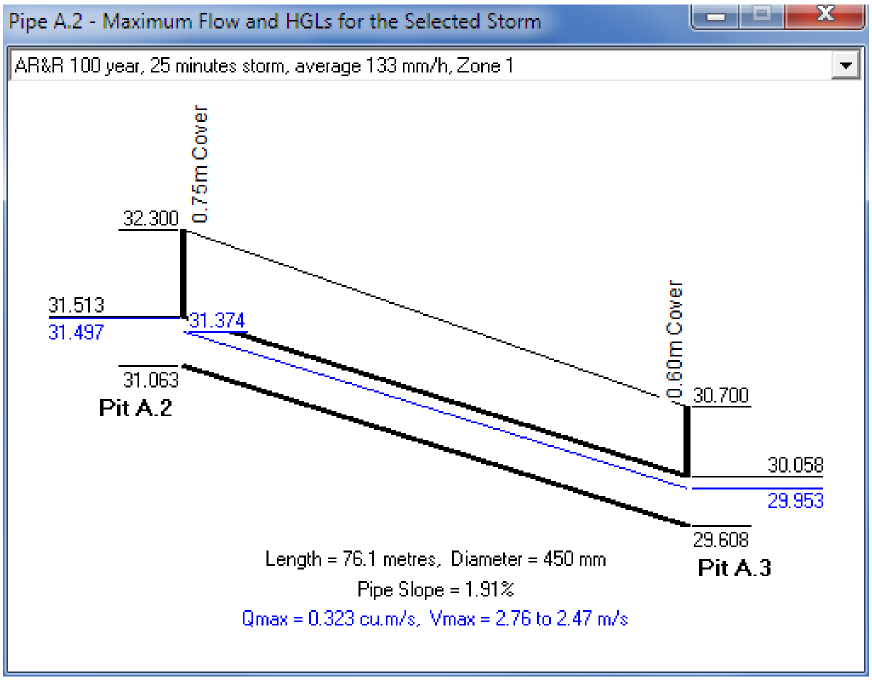


Figure A.18 Long Section Plot for a Pipe, Showing Pipe and Flow Characteristics

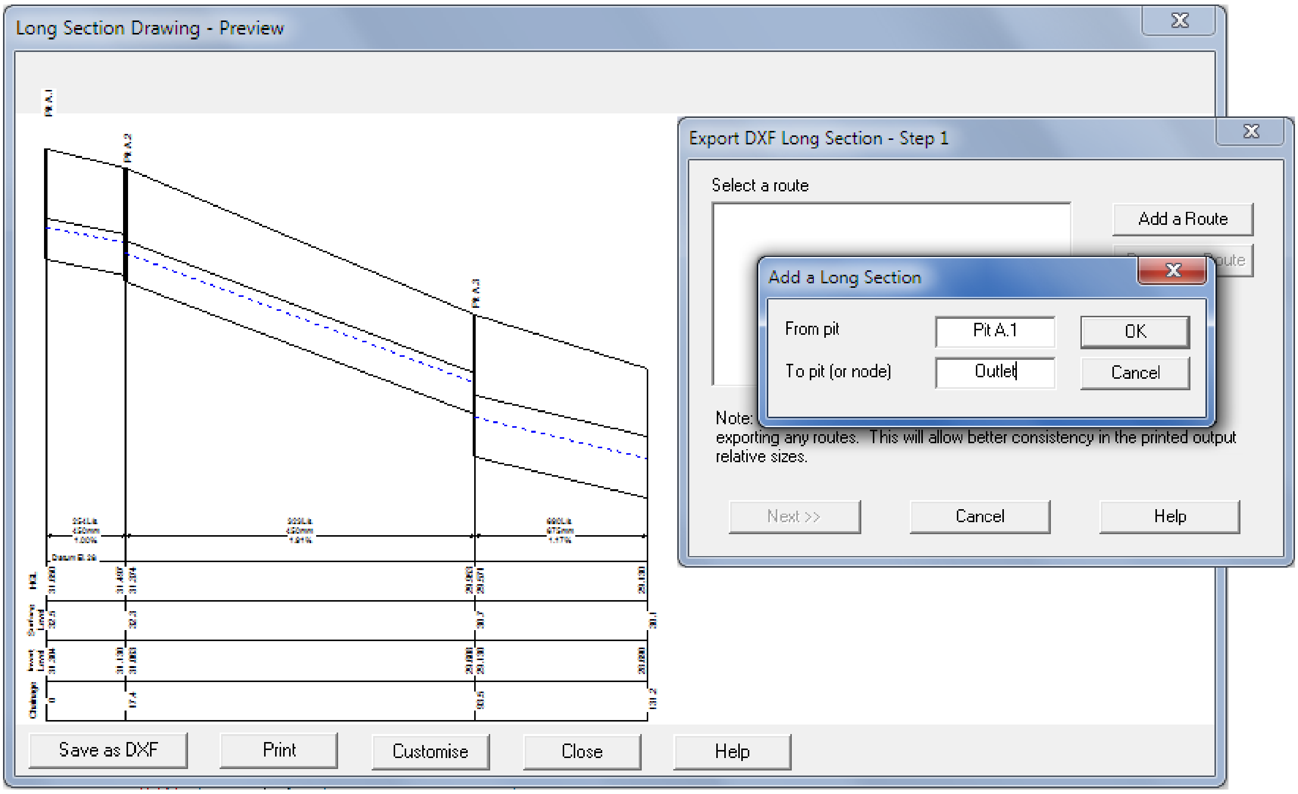
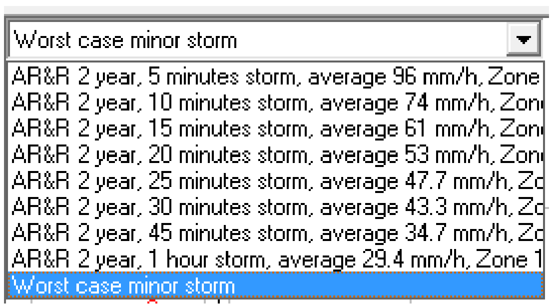


Figure A.19 Pipeline Long Section Plot, displayed prior to Transfer to a CAD Program

A.5.2 Viewing Pipe System Results



If a model loaded into the *Viewer* contains run results, you will see these straight away as coloured numbers, as shown in Figure A.20. Since the overflow routes will probably be the most critical they are displayed in **red**.

If this result comes from an ILSAX or ERM hydrological model, it will probably be the maximum flowrate out of a series of analyses of storm patterns. You can view individual patterns by selecting them from the drop-down menu at the top-left of the Main Window, shown to the right.

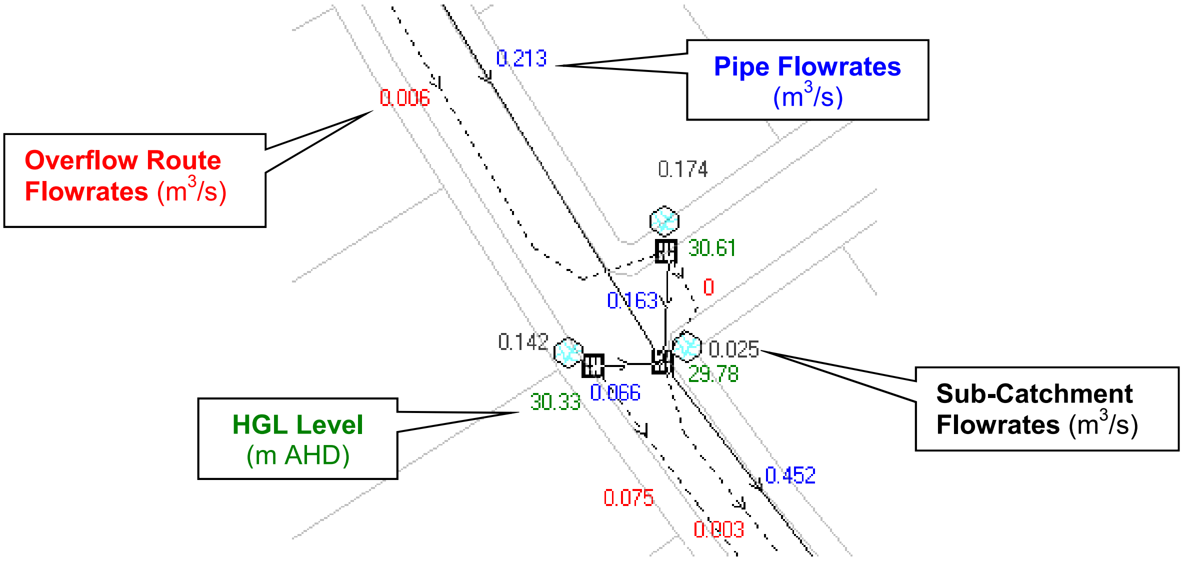


Figure A.20 Displayed Flowrates and HGL Levels

Note that flowrates in and out of a pit or node will not necessarily add to zero, as they may represent conditions at different times, or come from different storm events. More accurate checks involving hydrograph volumes are provided in the spreadsheet output of results.

It is worthwhile to check the run report by selecting the **Last Run Report** option in the **View** menu. This produces a report such as that shown in Figure A.21. This shows a warning that water is being lost from this system, which occurs when a pit overflows but no overflow route is provided to convey this overflow. In such situations the model should be amended. The message also indicates that there are no overflows from the pipe system and that freeboard is adequate, that is, the peak pit water level is more than the minimum freeboard allowed, normally 150 mm, to meet a requirement mentioned in Section 3.4.

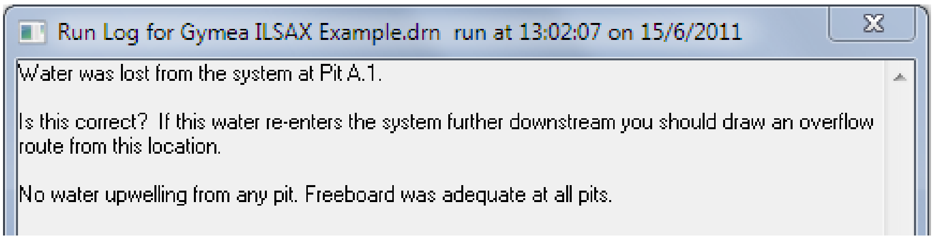


Figure A.21 Run Report

In designs there should be no upwelling or other problems at the Minor flowrate, but these can be permitted under major flow conditions, usually 100 year ARI storm events. It is also possible to view other characteristics using the **Customise Text…** option in the **View** menu. This changes the display to the form shown below.

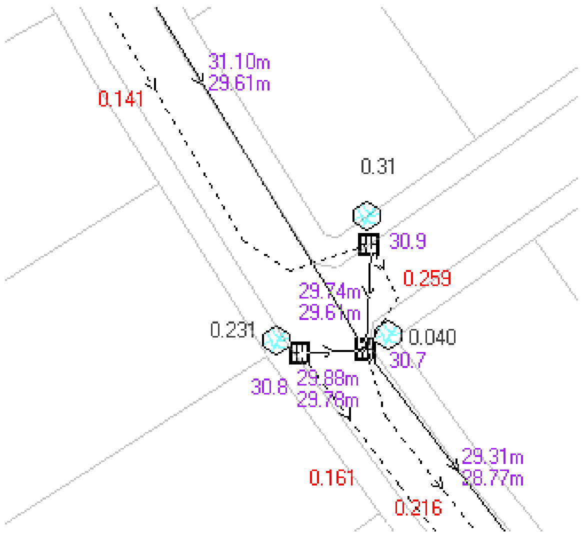


Figure A.22 Displayed Surface and Pipe Invert Levels

Results can be viewed in more detail using options in the pop-up menu displayed by right-clicking on components. These can display hydrographs and HGL plots as shown in Figure A.23 and long-sections of pipes (Figure A.18). Tables of results can also be displayed and exported to a spreadsheet via the Windows Clipboard.

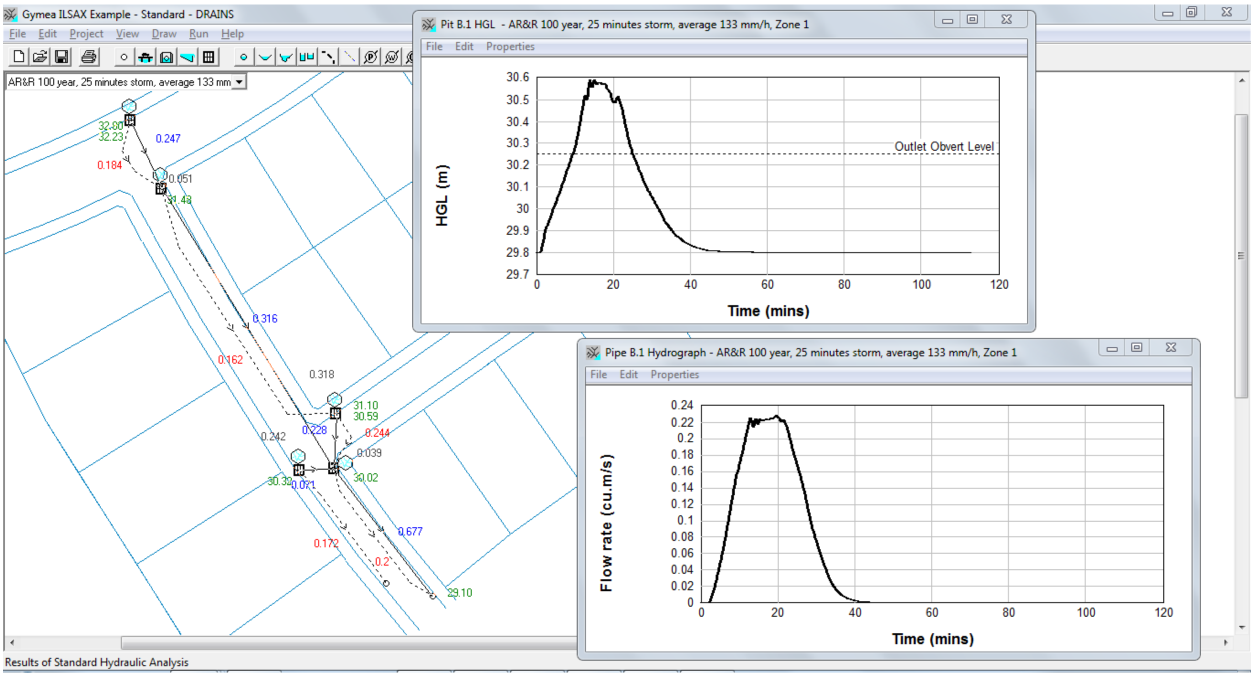


Figure A.23 Display of Hydrographs and Hydraulic Grade Lines (HGLs)

The most critical output will probably be the flow characteristics in overflow routes, which can be displayed by opening the property sheet for an overflow route, and going to the second page tagged **Cross Section Data**. As shown in Figure A.12, a picture of the section is shown, together with flow widths, depths, velocities and velocity-depth products. This can be used to check the critical characteristics for street drainage systems detailed in Section 3.5 – the allowable width and velocity-depth product. It can also be used to assess flood depths to be related to floor levels of existing or planned buildings.

The flow that is displayed in Figure A.24 may be greater than the rate displayed in the Main Window, due to an additional flow being specified to allow for overflows combining with flows from the sub-catchment through which they flow. This occurs when the number in the box labelled **% of downstream catchment flow carried by this channel** in Figure A.24 is greater than zero. Refer to the Manual and Help system for more information.

Reviewers should note that when the basic or standard hydraulic model (see Section 4.4) is used in *DRAINS* the flow characteristics in overflow routes are calculated by assuming uniform flow conditions along the overflow route. In fact, the flowrate will vary along the route. If the premium hydraulic model is applied, the water surface will be determined more accurately and it will be possible to display a long section as shown in Figure A.25. Therefore, when the standard or basic hydraulics are used, the flow characteristics should be considered as an indicator, rather than as an accurate estimate. Overflow route characteristics are also questionable for short routes and those running round corners.

Using additional spreadsheets included on the CD accompanying this guide, the *DRAINS* spreadsheet outputs can be converted to tables of the form shown in Figure A.26. This is from the Gymea ILSAX example. There is another that converts rational method results to tables employed by Queensland councils. These outputs present pit pressure change coefficients ('k values') developed by a procedure that looks up the tables presented in the *Queensland Urban Drainage Manual*. Details are provided in the *DRAINS User Manual* and Help system.

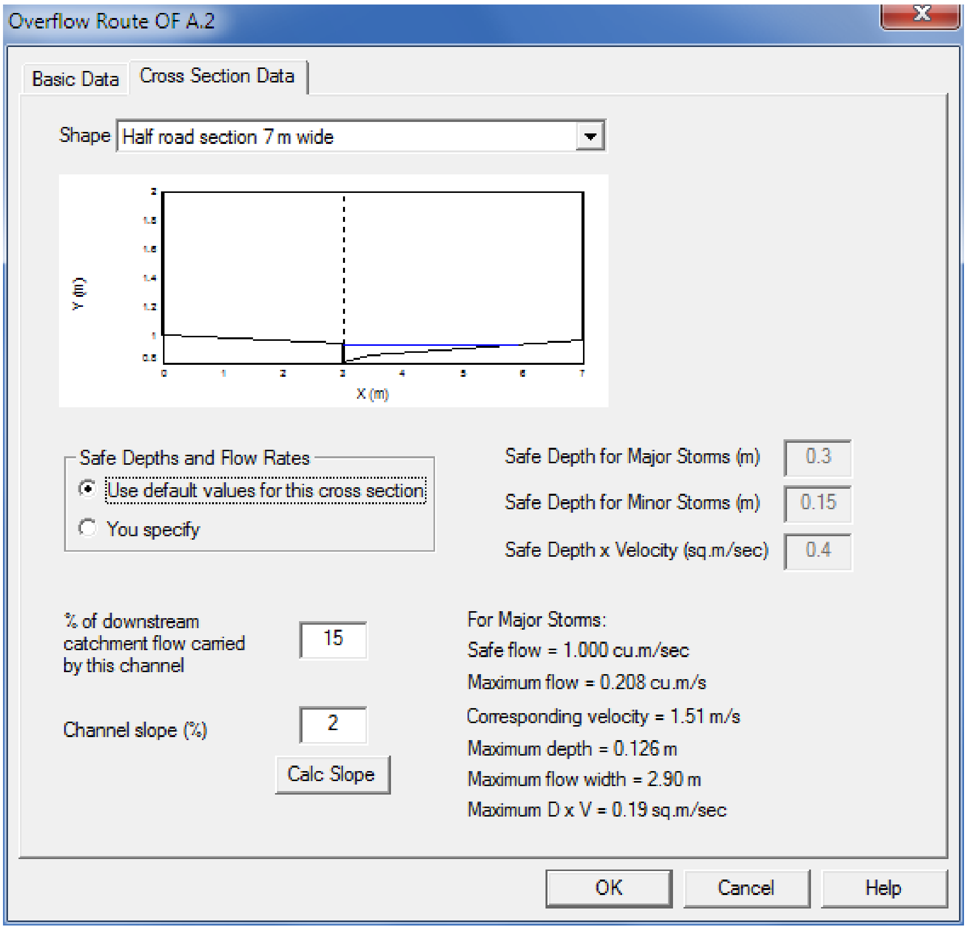


Figure A.24 Display of Overflow Route Flow Characteristics

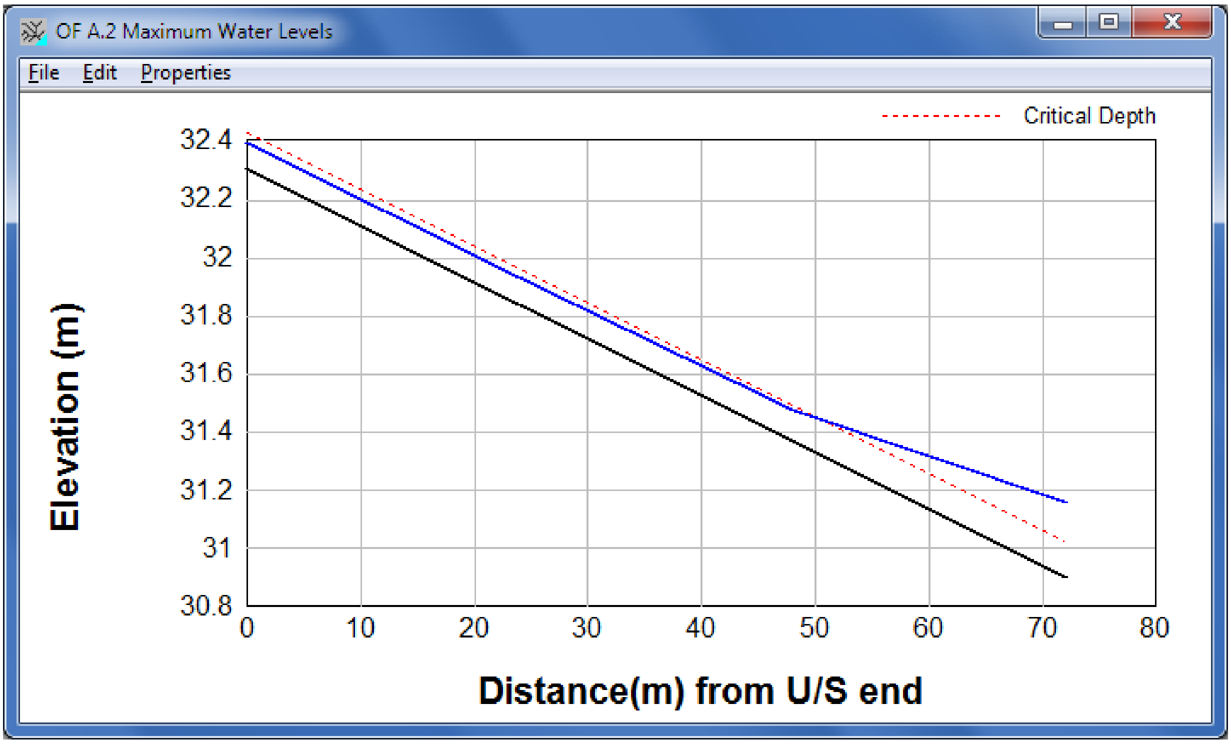


Figure A.25 Overflow Route Long Section from Premium Hydraulics Model

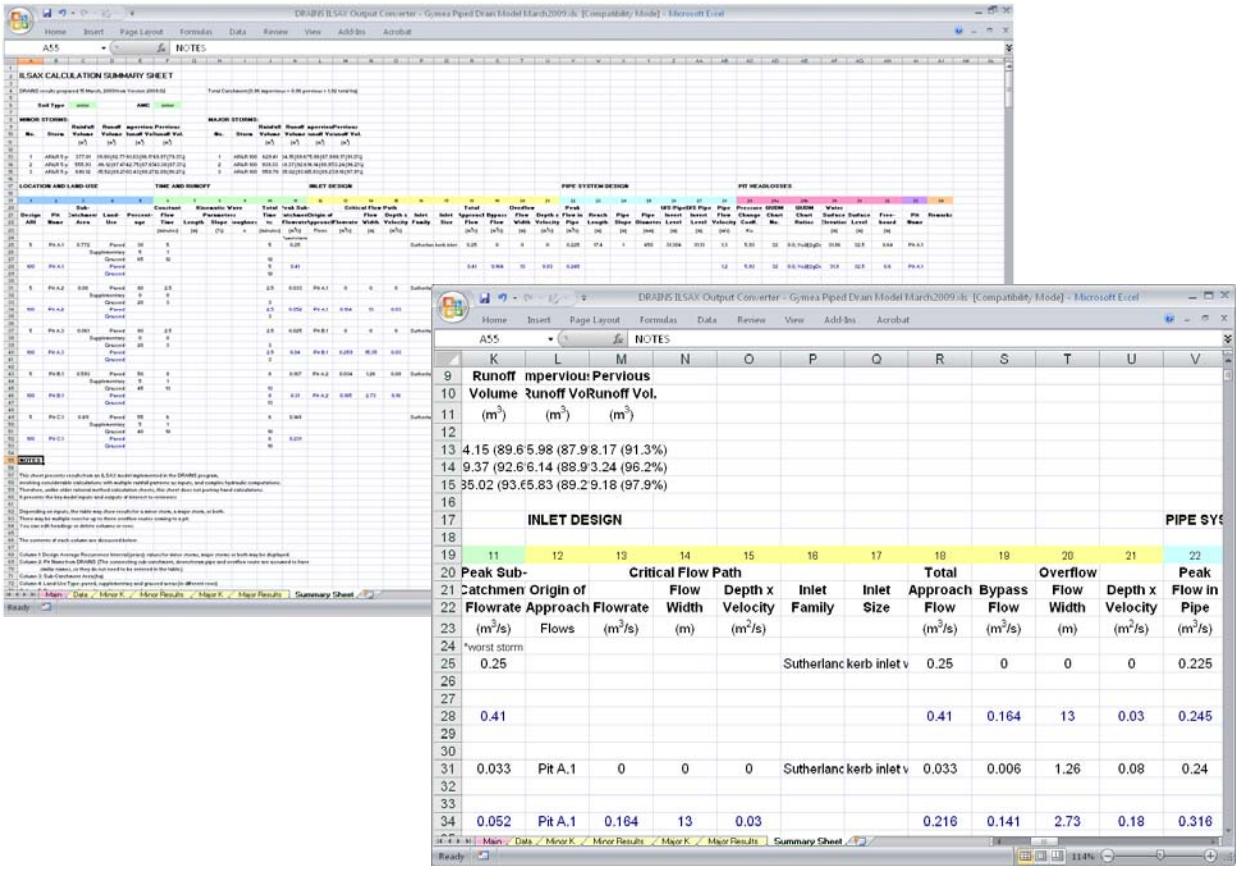


Figure A.26 Table for Gymea Design Example

A.5.3 Reviewing Stormwater Detention and Retention Systems

Detention basins in *DRAINS* usually involve three parts arranged as shown in Figure A.27 – a basin component, a pipe outlet and one or more overflow routes that represent 'high-level' outlets such as a weir overflow,. A sub-catchment can be attached directly to a basin, and channels and pipes can be directed into it.

The basin property sheet, shown in Figure A.28, specifies the type of 'low-level' outlet (pipe, orifice, sump, etc.) and a relationship defining storages, either an elevation-surface area table or an elevation-storage table. In the second page tagged **Infiltration Data** information can be added that will allow stormwater infiltration to occur through the floor and walls of the basin.

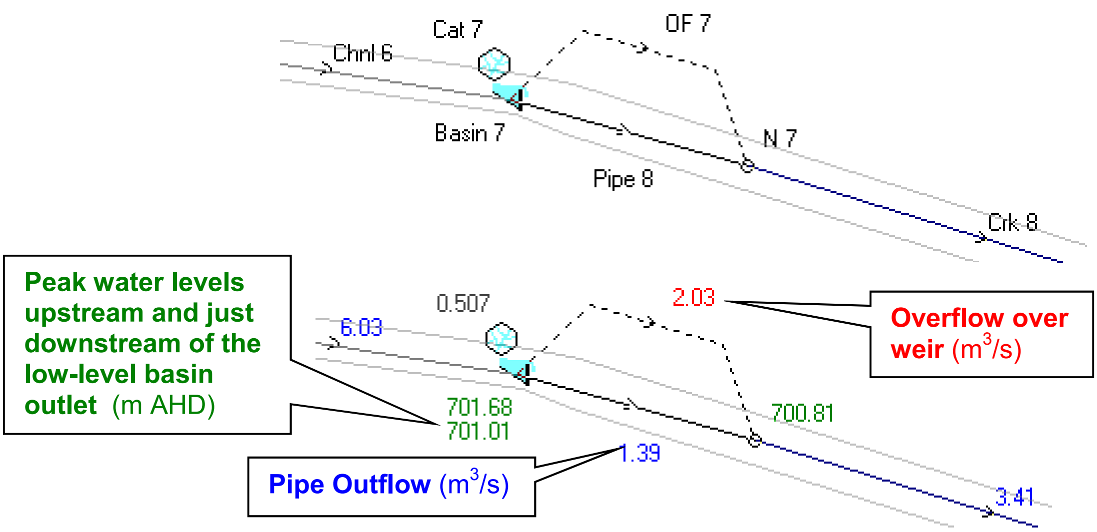


Figure A.27 Detention Basin Layout and Results

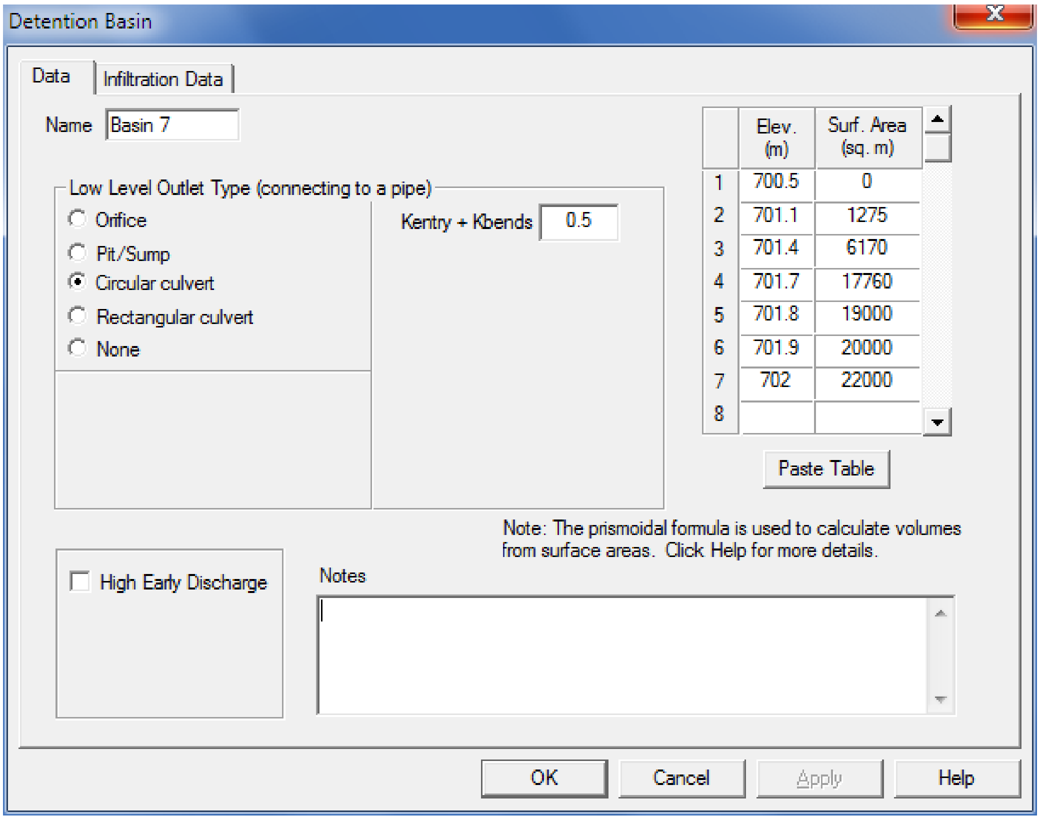


Figure A.28 Detention Basin Property Sheet

The pipe property sheet is the same as the usual sheet shown in Figure A.15, while the overflow route has three pages describing the weir control of the high-level outlet (Figure A.29) and the geometric properties of the overflow route carrying flows from this.

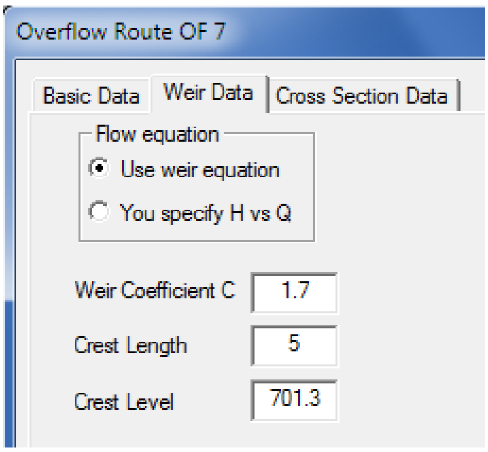


Figure A.29 Part of the Overflow Route Property Sheet for a Detention Basin

When a run is made, the results shown in the lower part of Figure A.27 are obtained, and the reservoir routing calculations can be viewed from the pop-up menu for the basin and the components connecting to it. Figure A.30 shows routed hydrographs.

Basins can take many configurations and multiple high-level outlets can be specified.

Reviewers should check that volumes in and out are consistent. There can be differences between these due to infiltration, to *DRAINS* cutting long drawn-out outflows short, and to basins being drawn down below the outlets at the start of a storm event. Inspection of the hydrographs and other plots will enable reviewers to trace the behaviour of the detention basin.

Some issues that arise with basins are:

- Use of multiple low-level outlets in parallel or series – The *DRAINS User Manual* describes methods for dealing with these. If tailwater levels are not high, overflow routes can model these accurately.

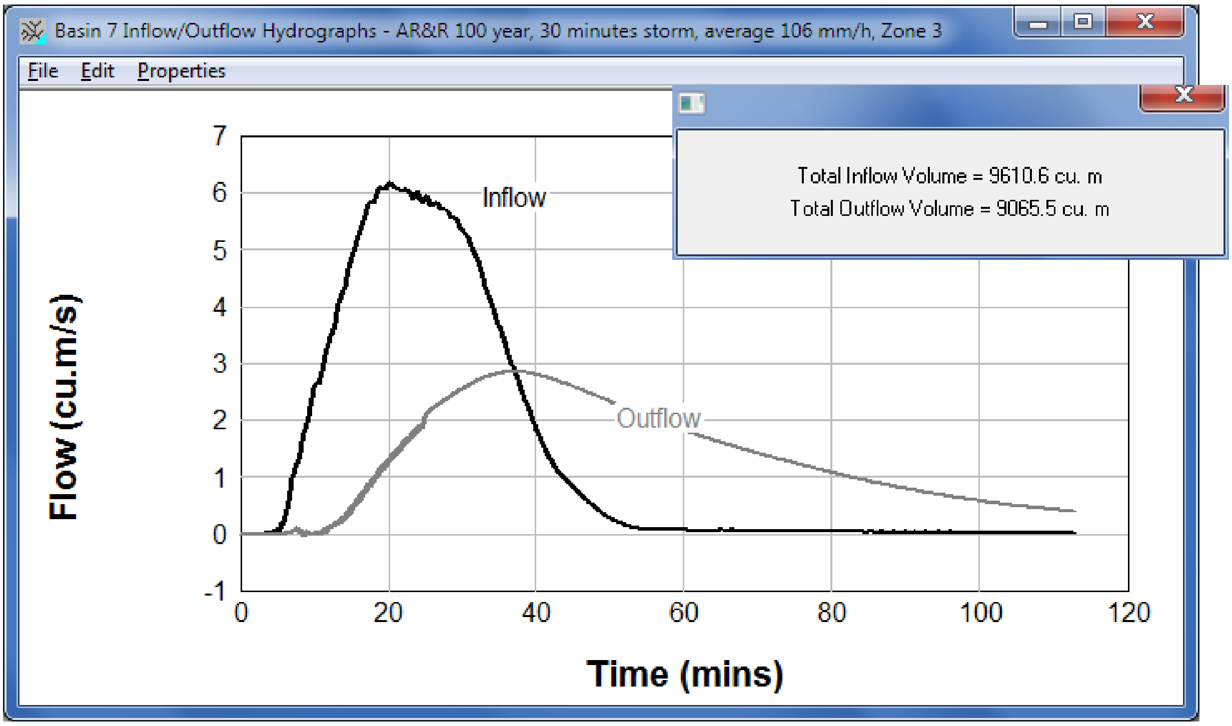


Figure A.30 Routed Inflow and Outflow Hydrographs for a Detention Basin

- Modelling of sumps or infiltration basins – It is possible to model basins without outlets, where water is disposed of by infiltration. *DRAINS* models the entry of inflow hydrographs and the slow draining of the basin, monitoring storage levels and enabling the storage volumes required to be defined.

One matter that frequently arises is how to model a requirement that post-development flows must not exceed pre-development flows. This can be difficult because many ARIs and storm durations must be considered.

When on-site detention systems were first introduced most authorities required only that 100 year ARI flowrates to meet this requirement, with some applying a more rigorous requirement such as ensuring that 100 year ARI post-development flows to be no greater than 10 year ARI pre-development flows. This was sometimes justified on the basis that the downstream pipe capacity was limited to, say, 10 year ARI, but was also a means of limiting flows at ARIs lower than 100 years to pre-development levels.

It has now become common to limit post-development flows to two levels, typically 2 and 100 year ARI, often justifying the lower level on environmental grounds, as a way of preventing erosion in natural streams carrying runoff from developments. Compared to only having to implement this requirement at the 100 year ARI level, this requires either (a) a more restrictive outlet and a larger storage volume or (b) double low-level outlets.

Since *DRAINS* can easily model multiple storm events, it is feasible to analyse all relevant design storms. For example, Table A.15 and Figure A.31 show results from the **`Sydney OSD Example with Results.drn`** model in which three storms have been analysed. (In practice, 6 to 8 storms would usually be required.

Table A.15 OSD Model Results

Storm Duration (h)	**Pre-Development Outflow** (m^3/s)	**Post-Development Outflow** (m^3/s)
10	0.027	0.024
20	0.032	0.025
30	0.034	0.025

This model contains both the pre-and post-development systems, so that they can be analysed together and the total outflows compared. Inspecting the results, it is possible to develop the following table of results from 100 year ARI storms.

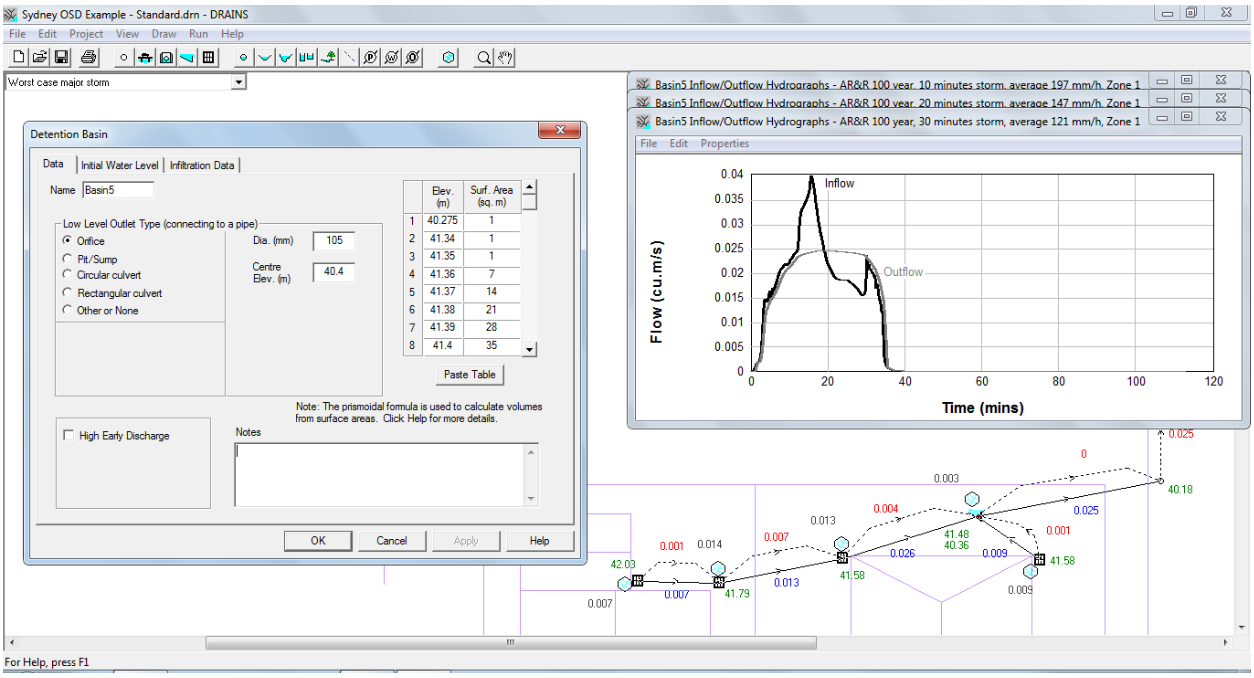


Figure A.31 On-Site Detention Model Results

Thus, it is possible to ensure that post-development flows peaks are held to pre-development levels for all storms analysed.

When modelling pre- and post-development conditions, it is important that the same hydrological model is applied to both cases, with adjustments to allow for increased development and imperviousness.

Reviewing Open Channel Systems

Open channel systems can be set up in *DRAINS* by specifying a number of reaches with appropriate cross-sections and parameters. Different procedures are applied for the basic calculations and the unsteady flow (standard and premium hydraulic model) calculations.

The **Toowoomba Estate Example with Results.drn file** on the CD defines a system containing both pipes and open channels, shown in Figure A.32. HGL and water surface levels at nodes and plots of longitudinal and cross-sections can be inspected.

If it is required to find a surface water level at a location along a channel, perhaps at the site of a proposed development, then a node should be located at this point. *DRAINS* will than specify calculated flow levels at this exact point.

A.6 Analyses

One of the main uses of *DRAINS* is the analysis of localised flood problems. It is difficult to define precise rules for this, as there are many variations in development projects and drainage systems, particularly in established urban areas.

The level of detail required and the handling of upstream and downstream drainage systems require judgement, balancing the accuracy required against the resources available, such as funding, information and time.

The use of sensitivity analyses, repeating calculations with different possible inputs, is probably the most powerful tool for examining and reducing uncertainties. For example, if tailwater conditions are uncertain, *DRAINS* runs can be made with different tailwater levels and the results assessed to come up with a reasonable but conservative estimate.

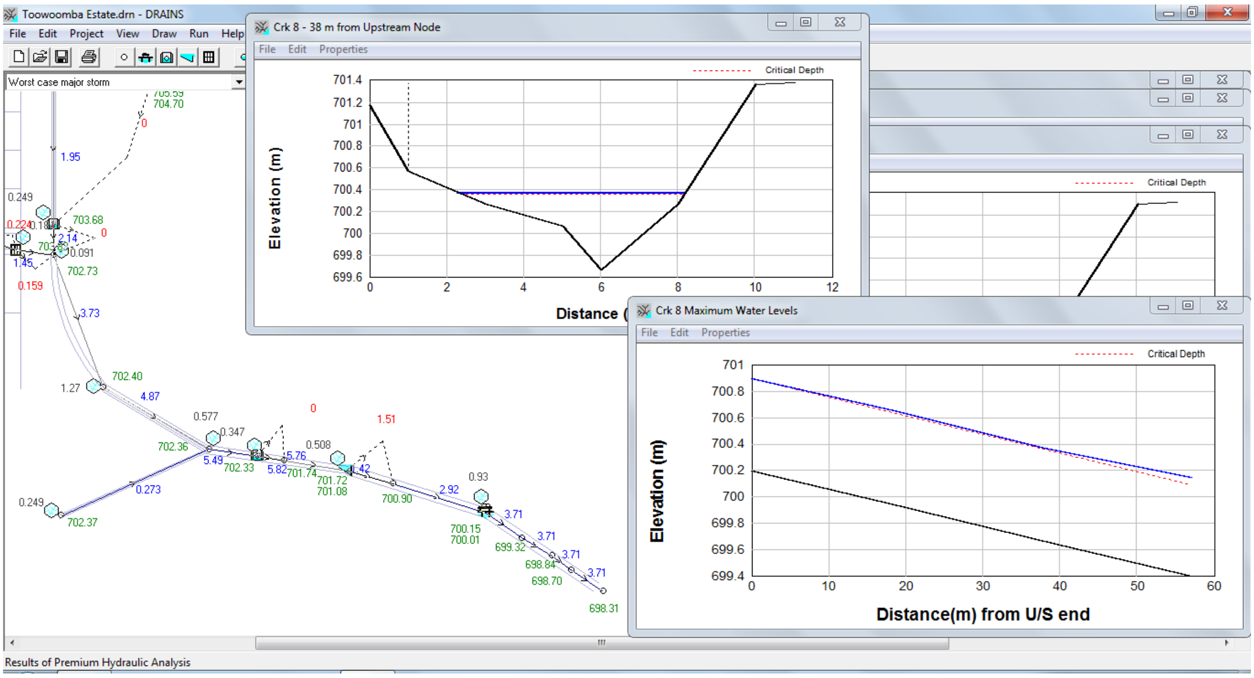


Figure A.32 Open Channel Model Results

Reviewers need to be satisfied that the analysis has been carried out correctly and will probably expect a conservative estimate. Generally, the more uncertain the conditions and the less experienced the modeller or designer, the more conservative the results should be.

Using the ILSAX model, *DRAINS* has been applied in detailed models of existing drainage systems of 2500 pits extending over 3 km^2. This is reasonable as long as all parts of the system are modelled in detail. However, a problem occurs when a point of interest such as a re-development site is located well downstream in a catchment. The drainage system near the site can be modelled in detail, but the difficulty lies in determining to what accuracy the upper part of the catchment drainage system should be modelled.

If all of the upper flow arrives as surface or open channel flows, or if all arrives in a pipeline, then it would be reasonable to apply a broad-brush method, such as modelling the entire upstream area as a single sub-catchment. But when upstream flows can arrive both on the surface and in pipes, it is necessary to provide further detail upstream. This may require all upstream pits and pipes to be included, although this can be done in a rough manner at locations away from the site. For example, getting pit surface levels and pipe lengths exactly right will not be important, but pit inlet capacities need to be described more accurately as these will define the proportion of upstream flows that enter the pipe system.

A.7 Conclusion

This Guide, originally issued with the *DRAINS Viewer*, aims to provide useful advice for reviewers and designers that will make checking and assessment processes more efficient. Further guidance is given in the publications on flood estimation in the reference list.

If you require more information, or have comments on the contents of the Guide, please contact the developers of *DRAINS*:

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